23 member countries representing 71% of the world's economy and 61% of the world's population.

Annual report 2017. IIASA conducts research into the critical issues of global

ABOUT IIASA

The International Institute for Applied Systems Analysis (IIASA) is an independent, international research institute with National Member Organizations in 23 countries in Africa, the Americas, Asia, and Europe. Through its research programs and initiatives, the institute conducts policy-oriented research into issues that are too large or complex to be solved by a single country or academic discipline. This includes pressing concerns that affects the future of all of humanity, such as climate change, energy security, population aging, and sustainable development. The results of IIASA research and the expertise of its researchers are made available to policymakers in countries around the world to help them produce effective, science-based policies that will enable them to face these challenges.

International Institute for
Applied Systems Analysis

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IIASA
Annual report
2017

Message from the Council Chair and the Director General

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In 2017, IIASA continued its mission of building excellence and strengthening capacity in systems analysis research by engaging in projects involving the development of new models and tools or the modification of some of its existing instruments. The strong relationships and collaborative partnerships that the institute has nurtured with research funders, academic institutions, policymakers, and individual researchers in its national member organizations, also provided valuable input to help shape the future of our changing world and provide realistic policy options for putting the world on a sustainable path.

Highlights from projects undertaken at IIASA in 2017 include, to name but a very few, restructuring financial networks to reduce systemic risk, understanding armed conflicts, meeting ambitious climate mitigation targets, and exploring possibilities for risk pooling in global breadbaskets. These and many other highlights from across the institute are available in this Annual Report.

The institute continues to attract and retain exceptional talent and currently has more than 830 research partner institutions in member countries. In 2017, 382 researchers from 48 countries worked at IIASA, while 2,421 associates and scholars visited the institute to do research, collaborate with research programs, and to attend IIASA-organized events. The research done at the institute resulted in 611 publications, of which 396 were peer-reviewed journal articles written in collaboration with over 1,600 coauthors from 159 institutions in 65 countries and regions.

The flagship Young Scientists Summer Program (YSSP) once again provided an opportunity for students from around the world to work with some of the leading scientists in their fields, with 49 participants from 26 countries included in the 2017 cohort. Since 1977, over 1,920 young scientists from 87 countries have benefitted from the program, which celebrated its 40th anniversary in 2017. The occasion was marked by a two-day conference attended by YSSP alumni, Council members, and distinguished scientists from outside of IIASA, who were invited to continue their ties with the institute, and consider the past and future of the YSSP. In addition, in 2017, 27 postdocs had the opportunity to enhance their skills in systems analysis, and IIASA scientists hosted or coordinated 98 events worldwide, including a number of workshops and activities specifically aimed at building capacity in the field.

Apart from engaging in excellent research, IIASA continues to play an important role in building bridges across political divides through science. In 2017, the institute was privileged to welcome Israel as a new member and successfully continued to collaborate on projects across the world, including in, among others, the greater Eurasian space and the Arctic.

The work of IIASA is made possible through the generous support of a range of organizations and individuals that share a belief in the principle that finding long-lasting solutions to the complex challenges faced by humanity today requires scientific expertise that is free from national interests. We would like to take this opportunity to thank our member countries and all our donors, for their continued support and generosity in 2017. We are truly grateful for their commitment to the mission of the institute.

Michael Clegg
Council Chair

Pavel Kabat
Director General

THE IIASA MISSION is to provide scientific insight and guidance to policymakers worldwide by finding solutions to global problems through applied systems analysis. In this way, the work helps to improve human wellbeing and protect the environment.

IIASA Strategic Plan 2010-2020

IIASA Research Plan 2016-2020

IIASA Research

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Employing entropy to study growth and resilience in systems

Restructuring financial networks to reduce systemic risk

Advanced Systems Analysis

Research by the IIASA Advanced Systems Analysis Program shows that the Basel III international regulatory framework for banks will not reduce systemic risk in the financial sector as planned. The results suggest that regulations should instead aim to increase the resilience of financial networks by restructuring them.

A resilient banking sector is a necessary condition for achieving sustained economic growth. The Basel III regulatory framework for banks is a new set of international banking regulations that were proposed after the financial crisis of 2007-2008, which aims to reduce the risk of a similar crisis in the future. The regulations, which are currently under intense discussion, would set higher requirements for bank capital and liquidity reserves and introduce capital surcharges for systemically important banks, that is, those that are "too big to fail."

One important aim of the Basel III framework is to reduce the risk of system-wide shocks in the financial sector. It is therefore essential that Basel III address the problem of systemic risk in the financial system in an appropriate way.

However, a recent study by IIASA researchers [1] showed that the capital surcharges would have to be much higher than those currently set to be effective, which would in turn lead to a severe loss of efficiency in the financial system.

The research is based on a state-of-the-art agent-based model of a financial system and the real economy developed earlier [2] [3]. Using the model, a series of numerical experiments, simulating different types of regulations and their impacts on risk and resilience in the financial system, were performed. The researchers found that replacing the currently proposed Basel III regulations with different regulation schemes that aim to re-structure financial networks, would be much more effective in increasing resilience while avoiding the loss of efficiency in markets. Such regulations could include smart transaction taxes based on the level of systemic risk, which IIASA researchers proposed in an earlier study [2] to reshape the topology of financial networks.

The study further highlights how important data-driven agent-based modeling has become as a tool to help identify the unintended consequences of regulations, and propose more effective solutions. As the international banking system is complex and intricately connected, it is important to analyze how regulations will affect financial networks from a systemic perspective in order to draft intelligent regulations.

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Further information

- Optimal behavior of systems
- New international banking rules would not prevent another financial crisis
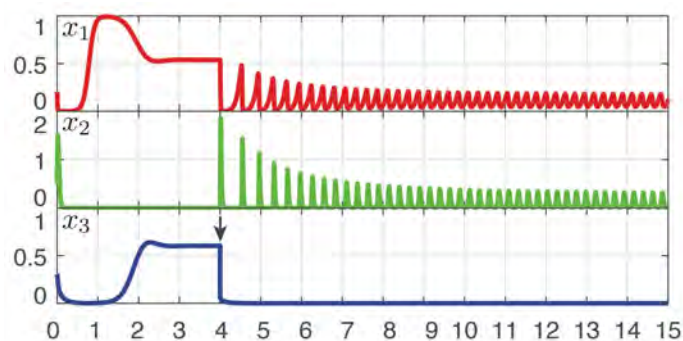
Understanding armed conflicts

Evolution and Ecology

Armed conflicts remain widespread around the globe, yet their dynamics are poorly understood. The recent introduction and analysis of a simple model enables basic insights into how military characteristics and recruitment policies affect the dynamics of these situations. In particular, the model shows when stationary and periodic stalemates are possible and how initial conditions and interventions influence the outcome of a conflict.

Owing to the prevalence and complex nature of armed conflicts, the interest in mathematical models that endeavor to understand them has increased in the last decades. Armed conflicts often involve more than two groups, which typically differ in their military characteristics and recruitment policies. Consequently, traditional descriptive conceptual models are of little help.

The new model has already produced interesting results for a simple case–an armed conflict between a governmental group and a rebel group [1]. The model indicates that an eradication of the rebel group cannot always be guaranteed, but that, instead, stalemates arise that can be stationary or periodic. Secondly, the model shows how outcomes are contingent on initial conditions. Lastly, when a conflict is trapped in a periodic stalemate, the model also allows the groups involved to determine when stepping up their efforts would have maximum effect.

Example of dynamics that may result in a simple model of armed conflict among three groups. One group has the military characteristics and recruitment policies of a governmental army (red), while the other two groups are typical of rebels (green and blue). Over time (horizontal axis), the abundance of different fighters involved in this conflict (vertical axes) changes. At the time indicated by the black arrow, one of the rebel groups (blue) is attacked and eradicated, leading to a resurgence of the other rebel group (green) and its subsequent periodic stalemate with the governmental army (red).

It is generally believed that the outcome of complex conflicts involving rebels and governmental groups cannot be predicted, because data are generally too scarce and unreliable. The results obtained with the new model show that the truth may be even less convenient, as the dynamics among the fighting groups can be extremely sensitive to initial conditions and parameter values [1]. This suggests that the outcome of a conflict may be practically unpredictable, even if very rich data sets were available. This finding, which is common to many complex adaptive systems, challenges the enthusiasm toward data-driven decision making.

According to the researchers, the results obtained so far have proven to be robust. The same results are recovered in a simplified model in which governmental groups are assumed to be purely defensive (i.e., their recruitment depends only on sustained injuries), while rebel groups are supposed to be purely fanatic (i.e., their recruitment depends only on inflicted injuries).

Further research is needed to address important open questions. Some of these are more academic in nature, such as whether armed conflicts exhibit deterministic chaos, peak-to-peak dynamics, and chaotic intermittence, while others are of greater relevance to decision makers, for example, how the models can describe the effects of temporary coalitions or of changes in power and intelligence. Answering these questions requires combining a deep knowledge of case studies with expertise in the theory of nonlinear dynamical systems.

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Collaborators

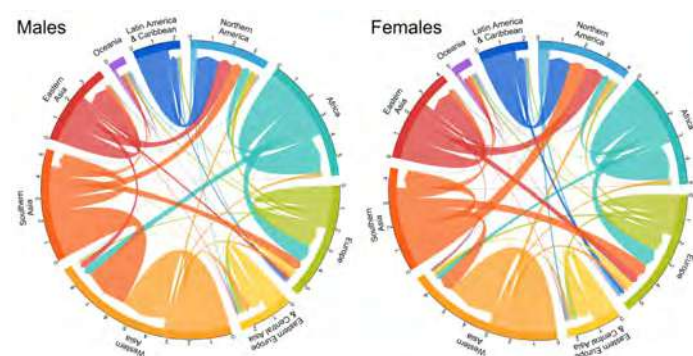- Polytechnic University of Milan, Italy

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Estimating global migration flows over the past decades

World Population

A new indirect estimation methodology, developed and applied by IIASA researchers, has quantified trends in global international migration flows over the past 55 years for the first time. These estimates provide a more comprehensive picture of past migration patterns than currently available figures in reported flow data produced by individual countries, or migrant stock data that do not capture the dynamic nature of movements over time.

Global international migration is an ever-changing process. Migrant stock data commonly used for the analysis of migration patterns, only capture part of the dynamic nature of international migration. An indirect estimation methodology, developed and applied by IIASA researchers, produces bilateral migration flow estimates that are demographically consistent with past population totals, births and deaths, and hence provides a more robust basis for understanding contemporary migration patterns where no comprehensive source of global migration flow data exists [1].

Estimated Migration Flows by Gender during 2010-15.

In their study, the researchers derived estimates of international migration flows by gender, between all countries, for five-year periods between 1960 and 2015. They found that, while estimated global migration flows generally increase over time, the percentage of the global population that migrates remains fairly steady at 0.65 of the global population over each five year period. This result supports similar findings in the migration literature on the lack of empirical evidence for the acceleration in global international migration, and suggests a shift in the directions of flows linked to major geopolitical and economic movements.

The bilateral estimates produced in this study quantify trends in global international migration flows over the past 55 years for the first time. Traditional migration receiving countries such as Australia, Canada, New Zealand, and the USA, for example, have seen continuously increasing numbers of migrants arriving. More recent growth is evident into countries in Northern-, Southern-, and Western Europe, while a growing number of migration flows were estimated along migrant corridors between countries in South Asia (such as Bangladesh, India, and Pakistan) to West Asia (such as Qatar, Saudi Arabia, and the United Arab Emirates), and from Asia to North America. In addition, large migrant transitions were also estimated in selected periods within Africa or Eastern Europe during times of armed conflict or political change.

The estimates produced can potentially be used as inputs into global population projection models. International projection-making agencies commonly use simplistic assumptions of net-migration measures derived as residuals from demographic accounting. However, past net migration can often be volatile and introduce bias when projecting populations [2]. The bilateral migration estimates produced in this research however, allow for more detailed scenarios to be formulated based on changes in migration patterns related to changing future push and pull factors in origin and destination countries, and corridor specific factors related to linkages between countries or groups of countries.

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Collaborators

- Asian Demographic Research Institute (ADRI), China
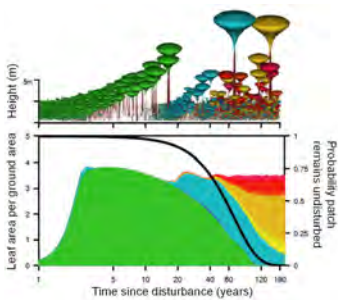
Further information

- New institute for Asian demographic research
- IIASA-JRC Centre of Expertise on Population and Migration

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Laying the foundation for a new generation of models

Cross-cutting projects

Dynamic global vegetation models (DGVMs) were first conceived at IIASA twenty-five years ago and have since become indispensable for understanding the biosphere and estimating ecosystem services. However, while their versatility is increasing as new processes and variables continue to be added, their accuracy suffers from the accumulation of uncertainty, especially in the absence of overarching principles controlling their concerted behavior.

The crosscutting IIASA project Dynamic vegetation models: The next generation (DVM) aims to address this problem by developing the foundations of a new generation of models centered on a 'missing law' – adaptation and optimization principles rooted in natural selection. Even though this missing law constrains relationships between traits, and can therefore vastly reduce the number of uncertain parameters in ecosystem models [1], it has rarely been applied to DGVMs. The project is working towards operationalizing this concept through scientific discussion and research collaboration in an international working group of leading experts from multiple disciplines coordinated by IIASA.
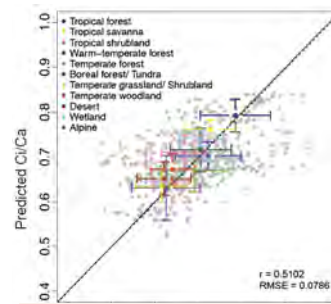

A universal model of photosynthesis reduces parameter uncertainty in vegetation models.

The project utilizes the convening power of IIASA to attract a wide range of members of the international scientific community of vegetation modelers to discuss and evaluate state of the art models, current limitations, and promising ways forward. Building on results of a recent DVM workshop, two papers are being prepared. The first of these is a review laying down a roadmap for the next generation of vegetation models,

A model of trait evolution and species coexistence recovers natural vegetation patterns from around the globe.

while the second is a perspective paper assessing the power of overarching organizing principles, including those of adaptation and optimization, for improving vegetation models.

Several studies have been conducted to explore these new concepts. These include an optimization-based photosynthesis model published in Nature Plants [1], a new model for adaptive tree growth [2], a study of the global effects of leaf optimization [3], an adaptation-based model of forest trait diversity published in PNAS [4], and a comment on mycorrhizal effects on global CO2 fertilization published in Science [5].

The findings of the above studies demonstrate the potential of adaptation and optimization principles for modeling plant and forest dynamics. In one of the studies, for example, researchers developed a model of trait evolution and species coexistence that recovers natural vegetation patterns from around the globe [4]. In this model, plant species inhabit a metacommunity of patches and differ in two functional traits, namely leaf mass per area and height at maturation. After a disturbance, vegetation development in a patch follows successional dynamics under height-structured competition

for light. The upper panel of Figure 1 shows the height of individual plants in a diverse community of species (colors) in a patch in the wake of a disturbance. The lower panel in turn, shows the corresponding prevalence of species (left vertical axis and colored areas) as the probability that a patch remains undisturbed decreases (right vertical axis and black line) for an average interval between disturbances of 60 years.

Using uniform parameters in conjunction with a least-cost optimality hypothesis, another model developed by researchers from the project predicts photosynthesis and associated leaf-internal-to-ambient CO2 partial pressures for multiple biomes (Figure 2). This model is driven by temperature, vapor pressure deficit, and elevation. The figure compares model predictions with observations from the global delta 13C dataset, with means and standard deviations indicated for each biome (colored lines). The model explains the observed variation among biomes, as shown by the resultant regression line (continuous black line constrained to pass through the origin), which is very similar to the 1:1 line (dashed black line) [1].

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IIASA Contributors	• Advanced Systems Analysis • Ecosystems Services and Management • Evolution and Ecology	**Further information**	• Dynamic vegetation models: The next generation • First workshop of the working group

Weighing up the costs of keeping cool

Air Quality and Greenhouse Gases

In October 2016, a global decrease in the use of certain greenhouse gases commonly used in a number of industries across the globe was agreed under the Kigali Amendment to the Montreal Protocol. A new study by the IIASA Air Quality and Greenhouse Gases program however, found that the cost burden of compliance with this amendment will be unevenly distributed across sectors and world regions, which justifies a redistribution of costs between now and the target date of 2050.
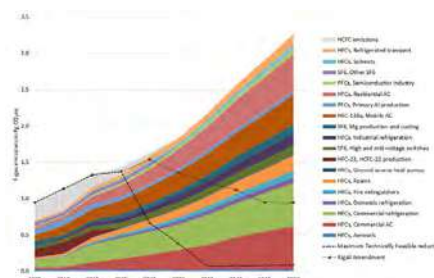
Hydrofluorocarbons (HFCs) are synthetically produced chemicals that are widely used as cooling agents in, for example, air conditioning and refrigeration systems, or as components in the production of, among other products, foams and aerosols.

Room air conditioners near Kahn market, New Delhi. © Anders Isaakson

Although they have strong global warming properties, these gases do not affect the ozone layer. As a result, manufacturers have been using them to replace the ozone depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) that are regulated under the Montreal Protocol. With increasing demand for the cooling and other services offered by HFCs and other fluorinated gases (F-gases) however, emissions of these powerful greenhouse gases are on the rise.

The GAINS model developed by IIASA researchers explores cost-effective emission control strategies that simultaneously tackle local air quality and greenhouse gases to maximize benefits at all scales. It assesses emissions on a medium-term time horizon, and specifies projections in five-year intervals until the year 2050. Researchers from the Air Quality and Greenhouse Gases program recently extended this model with a capacity to develop global emission scenarios for the F-gases, HFCs, perfluorocarbons (PFCs), and sulphur hexafluoride (SF6) [1].

Since its launch in 2006, GAINS has been implemented for the whole world, distinguishing 172 regions including 48 European countries and 46 provinces/states in China and India. The new resolution at the sector and technology level for each of the 172 regions is intended to provide sufficient detail to develop cost-effective emission reduction strategies for F-gases. When accounting for existing regional and national F-gas regulations, baseline F-gas emissions are expected to increase from about 0.7 to 3.3 Pg CO2eq between 2005 and 2050, of which HFC emissions alone make up about 2.9 Pg CO2eq in 2050. Growth in emissions is particularly pronounced in developing countries owing to an expected strong increase in demand for stationary and mobile air conditioning.

According to the researchers, the provisions of the Kigali Amendment could remove 61% of cumulative HFC emissions over the period 2018 to

Baseline emissions of F-gases (HFCs, PFCs, and SF6) 2005 to 2050 by source sector. HCFC emissions are summed up at the top of the graph.

2050 compared to expected emissions without implementation of the amendment [2]. It would be technically possible to remove as much as 84% if existing technology is employed to a maximum extent. Implementation costs are expected to remain very low in the coming two decades, but to rise sharply in the final decade leading up to 2050, unless future costs decline due to technological development and a full realization of expected energy-savings through careful implementation of alternatives to HFCs.

In a report prepared for the UN Environment Program on the impacts of the Kigali Amendment in Asia [3], the researchers also found that the expected CO2 reductions from electricity-savings linked to properly installed and maintained alternative technologies to HFCs, add about 10 to 12% of savings in greenhouse gas emissions to the total savings from a reduction in HFCs. Both estimates of costs and possible energy savings are potentially useful information for Parties to the Montreal Protocol when they next meet to set up the Multilateral Fund, which will alleviate some of the cost burden on developing countries to comply with the Kigali Amendment.

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Further information

- Global scenarios for F-gas emissions
- The GAINS Model
- GAINS: Comparing GHG Mitigation Efforts between Annex I Countries

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Employing entropy to study growth and resilience in systems

Advanced Systems Analysis

A study by researchers from the IIASA Advanced Systems Analysis Program, explored the relation between entropy-based indicators describing system efficiency and redundancy, and system growth and resilience to shocks. In another study they suggested ways to incorporate the properties of non-equilibrium and path-dependency into the traditional notion of entropy to better describe real-life human-earth systems.

Entropy is a concept that links the microscopic world with macroscopic (systemic) phenomena and defines the degree of disorder in a system. It was first introduced in physics to relate the velocities of particles (microscopic world) with temperature (macroscopic property). It is useful for describing and analyzing various complex systems consisting of a large number of interacting elements, where the concern of decision makers is on macroscopic parameters, while dynamics unfold at the micro-level of individual elements. In a closed system, entropy will always increase, while open systems, including all environmental and social systems, are able to manage the rate of entropy generation to some degree by maintaining a network structure.

Many real-life complex systems are networked systems. Food webs, for example, are networks of species feeding on one another, supply chains are networks of firms supplying intermediate goods to each other, and social systems are networks of people exchanging information and opinions–to name just a few. In systems, where the number of network elements is large and the connections are subject to so many factors that they can be seen as random to some degree, the concept of (information) entropy becomes applicable.

The study analyzed global commodity trade using the information entropy concept [1]. Its complex network structure arises from bilateral and multilateral trade agreements. The researchers found that trade agreements can make commodity trade networks more efficient and lead to more rapid growth in the volume of trade. However, these gains come at the expense of resilience to economic shocks, such as the 2009 global financial crisis, which decimated economies around the world. Perhaps counter intuitively, the results also showed that networks that had greater redundancies did not have to sacrifice growth.

Since complex systems are highly interconnected, traditional Gaussian statistics is not applicable to them. The statistics of complex systems is the statistics of power laws, where large and extreme events appear much more often than Gaussian statistics predicts. In earlier research [2], IIASA researchers suggested a way to extend the notion of entropy to systems that are networked and history dependent, to make it more applicable to complex

human-earth systems. In this study, they showed that simple path-dependent systems, such as situations with a winner-takes-all dynamic, can indeed be studied by means of developed generalized entropy. Winner-takes-all dynamics appear in many socioeconomic and environmental contexts, which show strong reinforcement and hence "fat tailed" distributions. This in turn implies that catastrophic events with high impacts happen more often than common sense suggests.

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Further information

- Interactions within systems

- Preferential trade agreements enhance global trade at the expense of its resilience

Building a sustainable future

Selected highlights

Ensuring a decent standard of living for all

Artificial reefs breathe new life into ecosystems

Playing for a sustainable future

Alleviating the tragedy of the commons
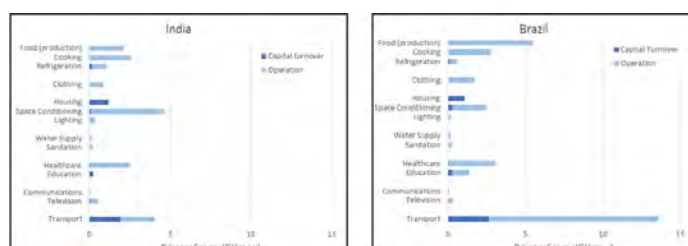
Meeting ambitious climate mitigation targets

Systems solutions for sustainability transitions

BUILDING A SUSTAINABLE FUTURE

Ensuring a decent standard of living for all

Energy

How much energy growth and what climate impacts are associated with meeting basic human needs? Bottom-up modeling of energy demand requirements in three countries—Brazil, India, and South Africa— shows that current energy supply could provide decent living standards if equitably used. A number of studies by IIASA researchers revealed opportunities for improving living standards while lowering emissions growth.

The Decent Living Energy (DLE) project quantifies the relationship between basic human wellbeing, energy demand, and greenhouse gases. In 2017, the project completed a methodological tool to measure the energy needs for poverty eradication and applied it in Brazil, India, and South Africa to generate policy-relevant insights on the energy needs for poverty eradication in different national contexts. The methodology builds on a conceptualization of material requirements of human wellbeing, or decent living standards [1]. It applies a set of tools from industrial ecology—including multi-region, input-output and lifecycle analysis, and building simulation models—to trace the energy use through the economy, to quantify the energy use associated with the goods and services needed to meet basic needs.

Illustrative energy requirements to provide decent living standards in India and Brazil, showing capital turnover and operating energy. Note: Space conditioning includes hot water production.

These methodological advances have made it possible for researchers to quantify the energy needs for meeting gaps in housing, nutrition, and health and education [2][3], and to reveal limitations in demand-side modeling in integrated assessment research [4].

DLE also investigated past trends in achieving living standards and related energy consumption patterns [5][6][7]. This research shows that income is a crude predictor of household appliance uptake in emerging economies, and that affordability and culture play a significant role. Although living standards have improved across the world due to growing income, clean cooking and improved sanitation consistently lag behind electricity and improved water provision. The researchers found that these gaps affect women's health in particular.

The energy needs for meeting the gaps in living standards are dominated by the construction of safe homes and transport infrastructure

to provide mobility to all [3][8]. What is particularly important for achieving the Sustainable Development Goals (SDGs) is that basic needs, such as food, education, health care, and basic utilities, are relatively inexpensive in energy terms. Another piece of good news is that micronutrient deficiencies in India, which affects over two-thirds of Indians, can be reduced by shifting cereal consumption from rice to coarse cereals, which would also reduce greenhouse gas emissions [9]. This work was presented to policymakers in India who are evaluating alternative pricing policies for cereals.

Going forward, this work will facilitate a country wise assessment of the synergies between mitigating climate change and achieving other SDGs. Additionally, it will provide a foundation for future research on building energy demand projections from end-use services, rather than from GDP. DLE research outcomes generate policy insights on the synergies between energy planning, climate mitigation, and social development goals.

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Further information

- Project website

Artificial reefs breathe new life into ecosystems (Evolution and Ecology)

Artificial reefs are becoming increasingly popular as a means of restoring and protecting coastal ecosystems and fishery resources. But do they work? A new study from the IIASA Evolution and Ecology Program suggests that the answer is a qualified yes.

Artificial reefs are man-made structures deployed on the sea floor, ranging from decommissioned vessels to purpose-built concrete structures. An artificial reef can provide new habitat for both juvenile and adult fish, thereby helping local populations to increase in abundance. At the same time, artificial reefs can reduce fishing pressures, because they restrict the types of fishing gear that can be used in their immediate vicinity. In particular, reefs hinder bottom trawling–an extremely efficient fishing method where conditions permit–as fishers run the risk of their expensive gear becoming entangled with the reef. Artificial reefs can also benefit tourism if they become places where divers can easily observe an abundance of diverse marine life.

Are artificial reefs worth the effort? It is well documented that artificial reefs indeed lead to local increases in many types of fish and shellfish. It is however more difficult to establish how much such increases are due to the enhanced productivity of local species, or because of the movement of individuals to the new reef from nearby areas–in the latter case, there is no increase in their overall regional abundance. Whether artificial reefs thus make economic sense remains uncertain, with some studies suggesting positive effects, while others have found no effects.

The Chinese government has invested heavily in artificial reefs [1]. In Shandong, a coastal province in eastern China bordering the Yellow Sea and the East China Sea, 170 artificial reef projects have been completed. The new reefs cover a total area of 150 square kilometers, that is, the equivalent of 21,000 football fields. The purposes of these reefs are manifold and include rebuilding fisheries, providing habitat for sea-ranching operations, and creating opportunities for tourism and recreational fisheries [2].

In this study, IIASA researchers assessed whether artificial reefs brought economic benefits in terms of increased fisheries revenues. The data were

Fat greenling (Hexagrammos otakii) is the most abundant species in the artificial reef sites. Source: Wikimedia Commons (CC-BY-SA-2.5).

Artificial reefs in Shandong, China, have a positive effect on both the revenue and the catch per unit effort for an average fish species (right half), but not when revenues and catches are aggregated over all species (left half). The difference occurs because some of the dominant species on the control sites do not benefit from the artificial reefs, overshadowing the positive effect on many sub-dominant species. The vertical lines indicate the 95% confidence intervals.
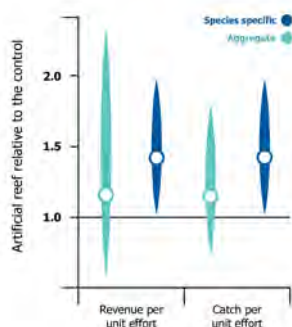
obtained from three artificial reef sites and nearby control sites in Shandong, and monitored by researchers from the College of Fisheries of the Ocean University of China. In terms of total revenues across all species, the researchers found no consistent differences between reef sites and control sites. However, when the data were analyzed at species level, different results became evident, with both catch and revenue obtained with the same effort being about 40% higher at the reef sites than at the control sites [2].

According to the researchers, the fact that the two types of analyses led to different conclusions is not surprising, as they address different questions. For the aggregate analysis examining total revenues, the results were largely determined by the responses of the dominant species that make up the bulk of the catches.

In particular, the species that dominated the control sites did not benefit from the artificial reefs, or were even negatively affected, hence, an overall effect could not be found. In contrast, when the researchers analyzed the data so that all species were given equal weight (without considering rare species), the sub-dominant species also became influential for the results. Among these, many species benefited from the artificial reefs [2].

This study highlights the need to be specific when asking sustainability questions such as what the benefits of artificial reefs are for fisheries. Although it is legitimate to focus on overall performance and/or average effects across species, it must be recognized that these represent distinct criteria that should not be confused when planning reef projects and assessing their outcomes.

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Further information

- Integrated Assessment of Fisheries

Playing for a sustainable future

Ecosystems Services and Management

IIASA teamed up with the Organisation for Economic Co-operation and Development (OECD) and the European Commission to test and play The World's Future game—a social simulation game developed by IIASA researchers on the interconnected nature of the Sustainable Development Goals (SDGs). The game sessions provided valuable insights on SDG implementation, while also offering an excellent opportunity for people from different working units and sectors to interact and exchange ideas.

With the adoption of the 2030 Agenda for Sustainable Development and the 17 SDGs, the international community created a comprehensive and indivisible set of goals attaching equal importance to environmental, social, and economic concerns. This acknowledges for the first time that transformation to sustainable and resilient societies cannot happen with a "business as usual", siloed, approach, and that a systems approach is a necessary condition for successful transformation. Translating this awareness into policymaking processes, however, remains a challenge. A full understanding of the interconnected reality of the SDGs remains elusive, and practitioners are seeking robust tools and guidance that can increase awareness and understanding that will eventually make integrated and coherent policymaking common practice.

To meet the challenge, a number of tools were developed to support policymakers and other actors in society in designing, implementing, and supporting coherent and integrated policies in pursuit of these goals and targets, and to consider transboundary and intergenerational impacts. One such tool is a social simulation game called The World's Future: A Sustainable Development Goals Game. The game was developed during the Systems Analysis Forum (SAF) exploratory project, "Systems Thinking for Transformation", that was led by the Ecosystem Services and Management Program (ESM), in collaboration with the Risk and Resilience Program and the Centre for System Solutions. This serious role-play game is based on scientific systems research, and functions as an experiential training and learning playground. The game challenges participants' understanding of sustainability dynamics and their ability to innovate and collaborate towards the global goals. Specifically, it aims to help players deepen their understanding of the complexities of the global system. This includes identifying and acknowledging the interdependency of actions in pursuit of the goals across policies, regions, and time; better understanding synergies, trade-offs, and feedbacks, as pursuing some goals and targets might undermine the achievement of others; as well as the ability to reflect on negotiation patterns, effective communication, and collaboration.

The OECD gaming session took place in June 2017 and was organized with the unit for Policy Coherence for Sustainable Development. The game prototype was played with an interested group of OECD sectoral experts and

Focal Points from OECD member states, who also helped test and further improve the game through their feedback. At the European Commission, two game sessions were organized with the Directorate-General for International Cooperation and Development's Policy and Coherence unit (DG DEVCO A1)–one session for the unit itself, and one session for staff from other DGs. Both sessions took place in Brussels in October 2017.

The World's Future game was very well received by both institutions, and participants agreed that it was a realistic representation of real world situations and challenges. Although many real-world complexities are expressed in the game, it is important to note that the game is not based on any specific national situation. This means that participants will not necessarily be able to draw direct policy conclusions from the game. However, as a capacity building exercise, players can gain multiple insights to clarify, inspire, and offer guidance in terms of policy decisions in their real-life contexts.

In addition to the sessions held at the European Commission and the OECD, many other groups across Europe, including some at the European Forum Alpbach, the National Youth Agency Austria, and the ScienceCenter-Network Austria, also played The World's Future game in 2017.

Feedback from participants

"It is a humbling and eye-opening experience for us as policy writers – to be confronted with the complexity of policy making in action and trying to find sustainable solutions, even in such a simplified version of reality."

"The game helped to get a better overview of how connected the world is and I can now better visualise the different sectors as one big picture. I also don't easily judge actors in different positions anymore, as one learns how difficult it actually is to achieve something together."

"One key take-away for me was an urgent need to better understand real incentives for different stakeholders to implement change in their industries. What makes them change? We don't really seem to know…"

"I got much clearer insight that policy making is actually messy, based on imperfect understanding of the system and incentives, as well as on imperfect information of what others are doing."

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- Centre for Systems Solutions (CRS)

Further information

- A Sustainable Development Goals game

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Alleviating the tragedy of the commons

Measures for protecting common goods — such as mitigating climate change or not overexploiting natural resources — are collectively beneficial, yet costly to the individual stakeholders that must invest in them. Common goods may thus be jeopardized by selfish agents, resulting in social dilemmas that often follow a pattern known as the 'tragedy of the commons'.

The tragedy, however, is not inevitable. There are abundant cases of common goods, even with weak regulatory regimes, that are thriving. In 2017, the Equitable Governance of Common Goods (EGCG) project focused on unpacking the complexities that characterize common-good governance based on predictions from game theory, plural rationality, and bounded rationality. This was accomplished through case studies, experimental games, experiential games, and agent-based and stylized models.

EGCG case studies provide evidence for the hypothesis that understanding and resolving the governance challenges associated with common goods require accounting for a plurality of values and preferences among stakeholders. In particular, it necessitates accounting for the four socially determined worldviews suggested by the theory of plural rationality: empirical studies have suggested that worldviews observed across a wide array of thematic domains and social contexts tend to cluster into individualistic, hierarchical, egalitarian, and fatalistic perspectives.

Among many case studies, the EGCG case on forest management in Nepal was one of the project's highlights in 2017. In 1979, the World Bank predicted that by 2000, 'no accessible forests will remain in Nepal' [1]. Today, however, Nepalese forests are flourishing. This success story is attributed to Nepal's community-based approach to forest conservation, which balances commercial timber interests with community control and entitlement conferred on forest user groups, all subject to stringent government regulation [2]. The Nepalese case study is embedded in a larger effort to rethink development aid in Nepal [3]. The rationale behind this new approach is that constructive and argumentative engagement of stakeholders with their plural rationalities is crucial for the governance of common goods.

With a focus on forest governance, the EGCG project has also devised three experimental games that explore the key predictions on common-good governance from game theory, plural rationality, and bounded rationality.

In 2017, the project highlighted the results from the first of these Forest Games [4]. The game demonstrates differential correlations between the average forest condition resulting from a group's harvesting and its average rationality or worldview, as revealed through a questionnaire developed by the researchers. The findings indicate that egalitarian worldviews improve a group's ability to preserve a forest (positive correlation), whereas individualistic and hierarchical worldviews have the opposite effect (negative correlations).

In the absence of options for real-world hands-on learning, 'serious role-playing games' can effectively provide simulated real-world experiences.

For this purpose, the EGCG project has developed several experiential games related to common-good governance.

The Water-Food-Energy Nexus Game, for example, which was jointly developed by the EGCG project and the IIASA Water Program, is an integrated simulation game that addresses the interrelated challenges of water, food, and energy production [5]. This game not only underscores the social dilemma involved in governing water as a common good, but also shows the added complexity of interrelated (nexus) issues with food and energy production.

In addition to the above, EGCG research strives to elucidate how the four worldviews recognized by the theory of plural rationality interact and how governance regimes — emerging bottom-up or imposed top-down — promote the successful management of common goods.

Another 2017 project highlight was the development and analysis of a first game-theoretical model of social dynamics under plural rationality. The researchers studied governance agendas whose alignments with individualistic, hierarchical, and egalitarian worldviews can change dynamically based on stakeholder influences. While the model is relatively simple, its dynamics are surprisingly rich, exhibiting several phenomena predicted by theory, such as the endogenous self-organized emergence of plural rationalities and cyclic social dynamics. The model results show how insufficiently inclusive governance agendas are constantly being undermined, leading to perpetual social change through which different worldviews become intermittently dominant.

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Further information

- Equitable Governance of Common Goods

Meeting ambitious climate mitigation targets

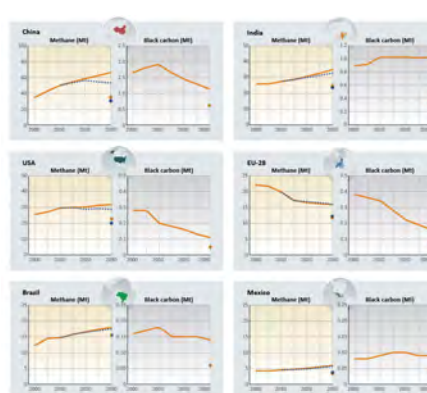Air Quality and Greenhouse Gases

Research shows that reducing the emissions of short-lived climate pollutants (SLCPs) will play an important role in meeting the 2°C target of the Paris Agreement. Although these emissions will be partially reduced as a consequence of carbon dioxide (CO2) mitigation, it will not be enough. According to the IIASA Air Quality and Greenhouse Gases (AIR) Program, additional, dedicated SLCP policies that will also deliver other benefits such as improved health will be needed.

Anthropogenic climate change is largely driven by human-induced changes in the composition of the atmosphere, including long-lived greenhouse gases that have lifetimes of approximately eight years or more, and SLCPs that have lifetimes of approximately 20 years or less. The challenge with SLCPs is that reducing their emissions may lead to undesired warming in the atmosphere. However, many SLCPs are also considered air pollutants that have negative effects on human health, crop productivity, and ecosystems.

The IIASA AIR program has been a forerunner in analyzing the role that SLCPs could play in meeting ambitious climate mitigation targets. In 2017, researchers concluded a number of important research projects in this field. These include an improved estimate of current and past emissions of black carbon (one of the notorious SLCPs) [1]; an analysis of how changing emissions of aerosol precursors have influenced the radiative balance of the planet in past decades [2]; an innovative analysis of the contribution of solid fuel cook stoves to the aerosol load in the atmosphere [3]; and an analysis of the interactions between SLCP mitigation and the sustainable development goals [4].

Led by Zbigniew Klimont and coauthored by Lena Hoglund-Isaaskson, both from IIASA, Chapter 6 of the 2017 UN Environment Program (UNEP) Gap report is dedicated to the role that SLCPs could play in achieving ambitious long-term global temperature targets. The team, which consisted largely of AIR program researchers and their current collaborators, highlighted that reductions in SLCPs are most effective when accompanied by reductions in CO2. Since CO2 and SLCPs often have the same sources, synergies can be reaped in reduction efforts. The researchers however caution that some pollutants are not co-emitted and need to be targeted individually. Moreover, because they have a shorter lifespan and thus influence the atmosphere in characteristically different ways, it is neither useful nor appropriate to translate SLCF mitigation to carbon-equivalent units. The authors recommend that long-lived greenhouse gases and SLCPs should be considered and targeted separately with policies tied to specific, non-convertible measures.

The UNEP report concludes that SLCF potential emission reductions are significant. It states that SLCP reductions will be an integral part of a strategy that aims to keep global temperature increases to less than 2°C, and that early reductions would not only help to slow the rate of climate change in the short term, but also provide substantial health benefits. In the

Baseline emissions of F-gases (HFCs, PFCs, and SF6) 2005 to 2050 by source sector. HCFC emissions are summed up at the top of the graph.

future, coreductions of SLCF because of CO2 reductions will play a role, but additional specific policies for SLCPs will be needed.

Over the past few years, the AIR program has also significantly extended and improved estimates of mitigation potentials and the costs of reducing SLCPs. This helps to better understand and design cost-effective strategies to reduce future climate change impacts in a complex world of interacting atmospheric processes and economic and environmental constraints.

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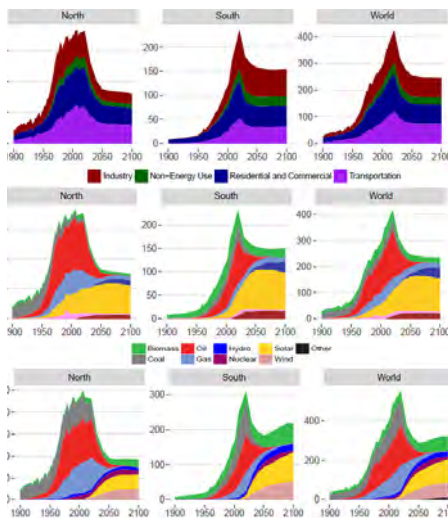
Further information

- Global emission fields of air pollutants and GHGs
- Impacts of Short-Lived Air Pollutants
- Benefits from Reducing Short-lived Climate Forcers

Systems solutions for sustainability transitions

Transitions to New Technologies

The Transitions to New Technologies (TNT) Program focuses on the systemic aspects of technological change and draws on empirical case studies, novel modeling approaches, as well as scenario studies and robustness analysis to inform technology policy choices from a systemic perspective.

In 2017, researchers from the program, in collaboration with colleagues from the Air Quality and Greenhouse Gases (AIR), Energy (ENE), and Ecosystems Services and Management (ESM) programs at IIASA, developed a Low Energy Demand (LED) scenario. The research is part of the Alternative Pathways toward Sustainable development and climate stabilization (ALPS) collaborative research project with the Research Institute for Innovative Technologies for the Earth (RITE) in Japan. This scenario is an innovative illustration of alternative pathways for sustainability transitions through an end-use driven approach of technological and behavioral change. A derived scenario variant will also provide the integrative pathway that will be used in the global research initiative–The World in 2050 (TWI2050)–that supports the successful implementation of the Sustainable Development Goals (SDGs).

End-use and demand-driven "peak energy" in a scenario of meeting a climate target of 1.5°C without negative emissions technologies. Final energy output (EJ, top panels) and primary energy extracted (EJ bottom panels) for the Global North, South and the World respectively. Declining energy needs result from rapid end-use innovations including new technologies, business models, and behaviors that yield step changes in efficiency and reductions in resource requirements, while providing for higher amenities and services in a rapidly developing world.

The LED project was initiated and completed as a fast track research input to the ongoing Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5°C. This project illustrates the comparative advantages offered by small, flexible research programs such as TNT that can act nimbly in response to important research opportunities. The study was also conducted as part of the longer-term ALPS collaboration framework with colleagues from RITE and involved a network of some 20 scientists from the AIR, ENE, ESM, and

TNT programs at IIASA, as well as representatives from TNT's network of alumni and research collaborators.

The objective of the study was to develop an illustration of an alternative strategy for meeting the stringent 1.5°C climate target formulated as an aspirational goal at the Paris climate negotiations. Instead of relying on large-scale supply side technological solutions, most notably a massive deployment of so-called negative emissions technologies (removal of CO2 from the atmosphere), the new alternative pathway focuses on end-use, changing forms of service provision like the sharing and circular economy, as well as granular technology options. This could provide a step-change in resource efficiency, leading to a demand-driven "peak energy" that would allow meeting the 1.5°C target without any need for negative emissions technologies and with significant co-benefits for the SDGs.

A specific characteristic of this alternative scenario is that it combines a rich scenario narrative based on the insights gained from TNT's research into historical technology transitions, and potential accelerators for systems changes with detailed modeling studies using IIASA integrated assessment models–GAINS, GLOBIOM, and MESSAGE–to examine the multiple implications of this alternative, rapid transition scenario. A paper is currently in the process of being published in a high-level journal, and the results have already been influential across almost all chapters of the forthcoming IPCC Special Report. A follow-up study extending this new scenario framework for an integrated approach to address SDG12 (responsible consumption and production) is currently being prepared for the TWI2050 initiative.

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Science into policy

Selected highlights

Informing policy decisions when disaster strikes

Consumers, development, and the future of wellbeing

Economic development and the food-water-energy-environment nexus in Ukraine

Trade-offs between cutting air pollution and worsening climate damage

The climate implications of today's energy policies

The state of world population aging

Informing policy decisions when disaster strikes

Risk and Resilience

SCIENCE INTO POLICY

Natural disasters in low-income regions have far-reaching impacts on all levels of society. A simulation framework developed by IIASA researchers can help policymakers to come up with informed short-term policies in an environment where they have limited resources and data to deal with issues like population displacement and food shortages, in a short timeframe.
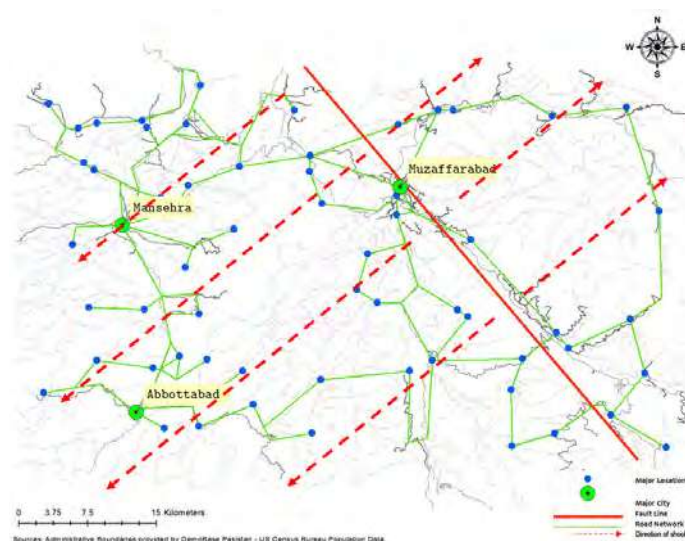
The effects of natural disasters in low-income regions (i.e., higher internal migration and low consumption levels) are the result of market failures that force the affected population to respond and adapt to the shock they face. In an environment with multiple locations and independent, but inter-connected markets, these transitions quickly become complex due to the feedback loops between the different market aspects.

To capture these continuously evolving interactions, researchers from the Risk and Resilience Program employed a model to analyze natural disaster-like shocks in low-income regions. They defined it in terms of six modules namely, production, consumption, buying, selling, income, and migration. The interaction between these modules produces a complete, closed economic system, allowing them to track the impact of a shock to one part of an economic region on the rest of the region. The aim of the model is to track how population distribution, income, and consumption levels evolve over time and in a defined geometrical space, in order to identify high priority issues such as food insecure populations.

The researchers applied their model to data from the 2005 earthquake in northern Pakistan. The region faced catastrophic losses and high levels of displacement in a short time span, and the accompanying labor, and goods market disruptions, resulted in a high level of food insecurity.

A geographic information system (GIS) map of the region was used as the physical environment in which the model of the artificial economy was situated. This included important features key to the functioning of the model, such as the precise locations of villages, cities, and roads. The model was calibrated to pre-crisis trends, and shocked using distance-based output and labor loss functions to replicate the impact of the earthquake. The model outputs showed plausible patterns, such as disruptions to the flow of goods, and population loss resulting in market imbalances. These results highlight patterns of consumption losses in specific locations over time, thus allowing for better identification of the most vulnerable hotspots of the earthquake-affected region.

The simulation framework presented by the researchers goes beyond existing modeling efforts that usually deal with macroeconomic long-term loss estimates. Policymakers will be able to use the information generated to devise informed short-term policies in environments where data is virtually non-existent, policy response is time-dependent, and resources are limited.

Propagation of shock in the 2005 Pakistan earthquake. Small dots represent villages and large dots represent cities. Green lines show the road networks. The solid red lines represent the fault line, and the dotted red lines the direction of the earthquake shock.

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Further information

• Risk management and adaptation

Consumers, development, and the future of wellbeing

As society recognizes and endeavors to combat threats to the environment, it is becoming increasingly clear that heterogeneity in human consumption behavior should receive greater attention to understand the impacts created by human development. The cross-cutting Socioeconomic Heterogeneity in Model Applications (SCHEMA) project focused on how accounting for socioeconomic heterogeneity in integrated assessments can improve both the prediction of global environmental change and their impacts on human wellbeing.

The project, which was completed in 2017, was a collective effort between four IIASA programs: Energy, Ecosystems Services and Management, Air Quality and Greenhouse Gases, and World Population. The aim was to generate a common layer of socioeconomic inputs that feed into at least three global models namely, the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), the Global Biosphere Management Model (GLOBIOM), and the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model. These inputs enabled the generation of more detailed representations of household diversity, specifically in aspects of basic subsistence, including food demand, cooking fuels, and related exposure to air pollution. The geographic focus of the project was India–a developing country with high socioeconomic contrasts.
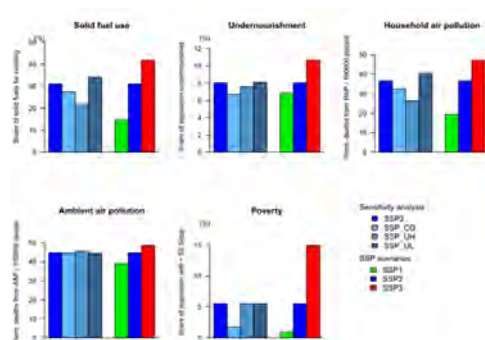
The SCHEMA project has led to significant methodological advances and substantive insights in the different IIASA domains addressed by the cross-cutting team. Existing IIASA models were modified to incorporate primary drivers of change into the projections and future scenarios of food demand and undernutrition, cooking fuels, and related health impacts from exposure to harmful substances emitted by these fuels (wellbeing dimensions) [1].

Detailed projections of future demographics and income inequality were generated for different states, taking into account urbanization rates and intra-national migration patterns. Income inequality projections accounted for increasing technology-driven skill bias and education improvements. These primary drivers were then converted into food and energy demand projections at national and state level. The results revealed that socio-heterogeneity significantly affects the results of the projections.

According to the researchers, understanding food and energy demand in the country is difficult without looking at patterns across socioeconomic groups. Average national GDP per capita masks poverty levels due to the unequal distribution of income within the country, and fails to account for the different levels of uptake of clean cooking fuels in urban and rural India. Furthermore, the relative contributions of higher and lower income groups to ambient air pollution vary significantly for different activities, for instance cooking in contrast to transport and other economic activities. In the case of

food consumption, the researchers performed a detailed analysis of Indian consumer expenditure over a period of twenty years (1993-2012), which allowed them to identify the most important drivers of change in dietary patterns over this period. Income distribution, urbanization, and aging were identified as key factors to understand the future of food demand and nutrition in the country. The Figure reveals the new capabilities of the IIASA models to project basic wellbeing dimensions under different socioeconomic futures.

In short, the project has laid a foundation from which multiple research and policy applications can be developed. The representation of different household groups enables the assessment of distributive impacts of various policies and policy shocks in all relevant sectors, such as carbon pricing, agricultural policies, or pollution control measures. Some of these policies can propagate through energy and food prices, where they have impacts on

SCHEMA wellbeing indicators (related to basic subsistence) for India in 2040 under different scenarios showing percentage of population (higher is less wellbeing). Shared Socioeconomic Pathways (SSP): SCHEMA-customized SSPs. SSP1: equitable world; SSP2: middle of the road; SSP3: unequal world. Three sensitivities SSP_UH/SSP2_UL: SSP2 with high/low urbanization. SSP_CG: SSP2 with constant Gini (low inequality).

air pollution, greenhouse gas emissions, and other dimensions of wellbeing. This kind of analysis can potentially help identify winners and losers by, for example, identifying groups that bear undue pollution exposure without proportionate contributions to emissions. Additional scenarios can also be devised to assess particular objectives, such as the Sustainable Development Goals (SDGs) and other national development objectives.

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Further information

- Socioeconomic Heterogeneity in Model Applications
- GAINS
- MESSAGE
- GLOBIOM

Economic development and the food-water-energy-environment nexus in Ukraine

Advanced Systems Analysis

A new collaborative research program between IIASA researchers and the National Academy of Sciences of Ukraine (NASU) has been set up to provide input to robust solutions and informed policies to ensure sustainable economic development pathways in Ukraine. A cornerstone of the program is the further development and application of the methodology of stochastic optimization, which is used to generate decisions under uncertainty in the food-water-energy-environment nexus.

In 2017, IIASA renewed its strategic collaboration with NASU on the topic of robust solutions for the food-water-energy-environment nexus, by committing to a five-year joint research program. IIASA scientists from the Advanced Systems Analysis (ASA), and Ecosystem Services and Management (ESM) Programs, will collaborate with colleagues from various other IIASA programs, and six NASU institutes (see list of collaborators). They will advance the methodology of stochastic optimization and its application to the integrated analysis of sustainable development of Ukraine. The program also involves policymakers and advisors to raise awareness of the critical dependencies within the food-water-energy-environment complex that has to be considered when planning sectorial development in the country.

To start the new collaboration cycle, the kick-off workshop and a series of follow-up meetings were organized in Kiev in September 2017. IIASA was represented by Yuri Yermoliev from ASA, and Tatiana Ermolieva from ESM. Future work on the program will build on the outputs of the 2012-2016 IIASA-NASU project, among which are recommendations for the 2015 Paris Agreement on Ukrainian energy sector reform, as well as contributions to a Ukrainian Common Cross-cutting Strategy of Agriculture Development.

The project addresses the challenge of building a methodological framework for decentralized optimization, to link agriculture, energy, and water sectorial models. The new framework will allow researchers to devise scenarios and produce recommendations in support of integrated policies in Ukraine that will reveal tradeoffs and synergies, notably under uncertainty, and at different spatial and temporal scales. This is to be based on earlier research [1].

In addition to research and science-to-policy applications, this collaborative project also undertakes capacity development activities. In

2017, a summer school was co-organized by NASU, Taras Shevchenko National University of Ukraine, Glushkov Institute of Cybernetics, and the Norwegian University of Science and Technology. About 50 students from six countries attended the course and benefitted from lectures presented by leading international scientists from various fields, including advanced systems analysis, operations research, and stochastic optimization.

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Collaborators

- Air Quality and Greenhouse Gases Program
- Energy Program
- Transitions to New Technologies Program
- Water Program
- Glushkov Institute of Cybernetics, Ukraine
- Scientific Centre of Aerospace Research of the Earth, Ukraine
- Institute of General Energy, Ukraine
- Institute of Economics and Forecasting, Ukraine
- Institute of Demography and Social Studies, Ukraine
- Institute of Theoretical Physics, Ukraine

Further information

- Workshop of the joint NASU-IIASA project
- Norwegian-Ukrainian Summer School
- Robust food, energy, water, and land management
- Integrated Modeling of Robust Solutions for food, energy, and water security management

Trade-offs between cutting air pollution and worsening climate damage

Air Quality and Greenhouse Gases

According to new research conducted by researchers from the IIASA Air Quality and Greenhouse Gases Program in collaboration with scientists in China and the USA, synthetic natural gas represents a trade-off between reducing air pollution and increasing greenhouse gas emissions in China.

China's industrial regions have been plagued by severe air pollution in recent decades and the situation has received worldwide attention thanks to photos of Beijing and other smog-blanketed Chinese cities. More than just an eyesore, China's smog has created a public health crisis that has led the Chinese government to declare war on air pollution. Air pollution contributes to cardiovascular disease, lung cancer and emphysema, among other illnesses and in China specifically, causes about 1.6 million people to die prematurely each year. This accounts for more than a quarter of annual deaths that can be attributed to air pollution.

Driven by this public health emergency and a desire to rely on its large supplies of coal, China has plans to substantially expand its production of synthetic natural gas (SNG). Around 40 SNG plants have been approved or are currently under construction in the country. In addition, as part of the Paris climate agreements, China has committed to peaking its CO_2 emissions by 2030 or sooner.

SNG is a fuel derived from coal that is relatively free of conventional air pollutants. For China, this fuel source represents a trade-off. Using SNG instead of coal could improve air quality and public health by reducing illness and premature mortalities due to air pollution, but it would also markedly increase CO_2 emissions, because creating synthetic natural gas from coal produces more CO_2 than burning the coal directly.

Given China's plans to produce SNG, the new study [1] examined possible ways for China to maximize improvements in air quality while minimizing the additional CO_2 emitted from the production and use of this fuel source. Yue Qin, a former participant of the Young Scientists Summer Program (2016), along with Fabian Wagner and other colleagues at IIASA developed a sophisticated modeling approach to estimate both health outcomes and carbon emissions under various SNG-use scenarios. Their goal was to determine whether the Chinese government might have options for optimizing deployment of SNG to minimize the climate penalty, while maximizing the health benefits of reduced air pollution.

The study examined the impact of switching from coal to SNG in three broad areas: electricity production, industry, and residential use. They found that switching to SNG in industry and electricity production would have little impact on smog-related deaths and cause a major increase in CO_2 emissions. However, the results also showed that switching from coal to SNG for residential uses, such as heating and cooking, would substantially reduce deaths due to air pollution and increase emissions of CO_2 to a lesser extent than the alternative. The smaller environmental impact of using SNG in the residential sector results because residential coal combustion in small stoves is inherently inefficient and has uncontrolled emissions of air pollutants. Coal combustion in the power and industrial sectors on the other hand, is more efficient and pollution control devices reduce emissions of health damaging air pollutants, thus reducing the benefits of switching to SNG.

Comparison of CO_2 emission changes and avoided premature mortality under various synthetic natural gas (SNG) allocation scenarios relative to the use of coal. Results for standard SNG scenarios all find increases in CO_2 emissions while results that include Carbon Capture and Storage (CCS) and the use of conventional natural gas (NG) all result in reductions in CO_2 emissions. Solid circles represent SNG without applying CCS, and open circles represent SNG with CCS applied during SNG production. Solid triangles represent the outcome when conventional natural gas is used without CCS. We assume that electricity provided for SNG_CCS is from natural gas combined cycle (NGCC) power plants using CCS.

SNG plants convert coal to a form of natural gas by a variety of methods that are typically energy intensive. As a result, it is a less efficient fuel than coal because of the energy involved in the gas's creation. The researchers found that using synthetic natural gas to generate electricity, for example, results in 60% more CO_2 emissions than using coal-fired generators.

One benefit of SNG is that toxic sulfur and nitrogen compounds are removed from the coal as part of the production process. Compared to coal-fired electric plants, this difference is relatively minor, as modern coal plants remove much of these pollutants. When SNG is however used in the residential sector, it produces far less pollution than the use of coal.

The study concluded that deploying synthetic natural gas in the residential sector would substantially improve air quality and reduce premature deaths associated with outdoor air pollution with the smallest increase in CO_2 emissions compared with the power and industrial sectors. However, the results also indicate that in no case can SNG simultaneously meet the desire to improve air quality while reducing carbon emissions.

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Further information

- Synthetic gas would cut air pollution but worsen climate damage in China

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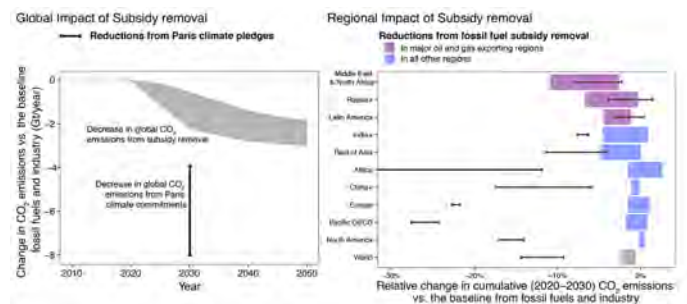# The climate implications of today's energy policies

Energy

What do today's energy policies add up to and how do they differ by region? Although climate change is a global problem, the policies to address it will be enacted at the national and local level. We need to understand the emissions implications of today's energy policies to know if we are on the right track to meet global climate targets and what needs to be clarified within policy pledges to reduce uncertainty. Two recent papers from the IIASA Energy Program further our understanding of today's policy proposals and their regional implications.

A study published in *Nature Communications* [1], carried out the first comprehensive uncertainty assessment of countries' national climate pledges put forward during the Paris climate agreement (known as nationally determined contributions or NDCs) at both the global and regional scale. It robustly shows that current proposals are both imprecise and inadequate. The vagueness in pledges results in a large spread in what emission levels can be expected for the year 2030, which even if strengthened afterwards would fail to achieve the ambitions of the Paris Agreement's temperature goal. The study identified China and India as two regions that contribute most to the overall uncertainty. As international negotiations are currently under way to define future rules for the formulation of and reporting on national pledges under the Paris Agreement, this study proposes several improvements to the NDCs reporting process, which would reduce overall uncertainty and increase accountability within international climate policy based on the most up-to-date science.

Another study led by IIASA researchers, published in *Nature* [2], looked into the global and regional effects of removing fossil fuel subsidies. It found that although fossil fuel subsidies amount to hundreds of billions of dollars, removing them would only slightly slow the growth of CO2 emissions, with the result that they would only be 1–5% lower by 2030 than if subsidies had been maintained. This equates to 0.5–2 gigatonnes (Gt/year) of CO2 by 2030–significantly less than the voluntary climate pledges made under the Paris Agreement–which add up to 4-8 Gt/year and are themselves not enough to limit warming to 2°C. Although the global effect on emissions is low, the impact varies between regions. The largest effects of removing subsidies were found in regions that export oil and gas, such as Latin America, the Middle East, North Africa, and Russia. In these regions, the emissions savings caused by subsidy removal would either equal or exceed their climate pledges. It is also these oil and gas exporting regions whose government budgets are most strained under low oil prices and for whom subsidy removal would thus be a welcome relief.

The regional differences highlight one very important aspect of subsidy removal that needs to be taken into consideration: the impacts on the poor. Fortunately, the highest numbers of poor people are concentrated in the regions where removal of subsidies will have the weakest effect on

CO2 emissions. Removing subsidies in richer oil and gas exporting regions would therefore provide significantly greater emissions savings and have a less detrimental impact on the poor.

In 2017, Energy Program research outreach fed directly into several international and regional policy processes, as well as into the broader scientific community. The insights of the *Nature Communications* paper were featured in the UN Environment Programme Emissions Gap Report [3], which provides an annual overview of the state of the science on climate action and in which the IIASA Energy Program has been taking up leading roles. Energy Program researchers were invited to present their insights at the UN Framework Convention on Climate Change Research Dialogue, the EU Issue Group on NDCs, and at a special session dedicated to the implications of the Paris Agreement at the Fall Meeting of the American Geophysical Union, the world's largest geoscience conference. The *Nature* paper was also covered by several news outlets including *Scientific American*.

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Further information

- Removing fossil fuel subsidies
- Nexus blog

The state of world population aging

The rapid increase in both the number and proportion of older persons in the five BRICS countries (Brazil, Russia, India, China, and South Africa) will have multifaceted implications for social and economic development. The first BRICS Meeting on Aging organized by the United Nations Population Fund (UNFPA) China provided a comprehensive review of developments in the field of population aging in these countries.

In 2015, BRICS countries were home to over 380 million older persons aged 60 and above. This represents about 42% of the world's population and the trend is projected to move upwards. Such a rapid increase in both the number and proportion of older persons will have multifaceted implications for the social and economic development of these countries, as well as for their social and economic transition in the coming decades.

The first BRICS Meeting on Aging organized by the United Nations Population Fund (UNFPA) China, provided a comprehensive review of developments in the field of population aging in BRICS countries. In particular, discussions during the event focused on common challenges faced by these countries, analyses of national experiences in coping with, and harnessing opportunities presented by aging, and the presentation of findings and recommendations for BRICS countries and others.

Policymakers, academics, students, and private sector representatives from BRICS countries, attended the event. Invited participants from other countries also took part in the discussions to provide wider and in-depth input on meeting topics.

As an established expert on aging in Russia and beyond, World Population Program Deputy Director Sergei Scherbov was invited to attend the meeting and brainstorm with other participants on how to promote collaborations on aging among BRICS countries. He gave a presentation on the state of world population aging as measured using the newest indicators developed at IIASA.

Scherbov, together with Warren Sanderson, has been developing new measures of age and aging in demographic research for many years. They suggest broadening research methods to account for significant increases in life expectancy, as the focus on chronological age of people alone provides a limited picture of the process–one that is often not appropriate for either scientific study or policy analysis. Their groundbreaking results have been published in Nature and Science, as well as in other high-level journals. Scherbov is principal investigator of the Reassessing Aging from a Population Perspective (Re-Aging) project at IIASA that, among other things, ascertains the extent to which advanced societies are actually aging in multiple dimensions, including health, cognitive abilities, and longevity.

The 2017 meeting on aging included three components: a) Responses of BRICS countries to population aging; b) Data on aging in BRICS countries; and c) Innovative practices on aging in BRICS countries.

The meeting was jointly hosted by the China National Committee on Aging (CNCA), Renmin University of China (RUC), and the United Nations Population Fund (UNFPA) in China, and organized by the China Research Centre on Ageing (CRCA), and the Institute of Gerontology at RUC.

The 1st BRICS Meeting on Aging took place in Beijing, China from 6 to 7 December 2017.

https://youtu.be/Bq9_uj9xghk

Further information

- Reassessing Aging from a Population Perspective (Re-Aging) project
- The state of world population ageing

Education and training

IIASA remains committed to strengthening the knowledge and abilities of researchers in systems analysis by training early-career researchers and demonstrating the value of its integrated models in workshops around the world. The Young Scientists Summer Program and Postdoctoral Programs in particular, provide vital capacity building in this field.

IIASA Postdoctoral Program

The Postdoctoral Program allows early-career scientists to research a topic related to the scientific agenda at IIASA and hone their skills in systems analysis. Postdoctoral fellows at IIASA are funded with support from the institute and two honorary fellowships established in honor of Dr. Peter de Jánosi, IIASA Director from 1990 to 1996, and Luis Donaldo Collosio, a former IIASA researcher who was assassinated in 1994 while campaigning for the President of Mexico.

In addition to the above, IIASA has been establishing bilateral postdoctoral fellowship programs funded by national member organizations (NMOs) since 2008. These programs are an effective way for NMOs to increase the number of its nationals who are postdoctoral fellows at IIASA, and to develop system analytical expertise among its researchers. IIASA currently has bilateral postdoctoral fellowship programs with Brazil, Finland, Mexico, the Republic of Korea, and Sweden.

In 2017, there were a total of 27 postdocs at IIASA. This included, 14 funded by IIASA, seven funded by NMO bilateral postdoctoral fellowship programs, two funded by the Peter de Jánosi fellowship program, and one funded by the Luis Donaldo Collosio fellowship program.

Along with the Brazil bilateral postdoctoral fellowship program, IIASA established a Brazil doctorate-sandwich program funded by the Brazilian NMO. The program will support PhD candidates spending three to twelve months at IIASA developing their doctoral research program. IIASA hosted three doctorate-sandwich students from Brazil in 2017.

Postdoctoral fellows in 2017

https://youtu.be/IQoeEyOsrrI

Young Scientists Summer Program

For three months every summer, the flagship Young Scientists Summer Program (YSSP) provides an opportunity for around 50 to 55 PhD students to work alongside IIASA researchers. During their stay, each participant is required to prepare a research paper. Many of these papers are published in prestigious journals. Since 1977, over 1,920 young scientists from 87 countries have benefitted from the program. The 2017 program hosted **49 participants from 26 countries**.

In June 2017, the YSSP celebrated its 40th anniversary. This was marked by a two day conferenece in Laxenburg. YSSP alumni from 1977 to 2017, IIASA Council members, and distinguished scientists from outside of IIASA were invited to renew their ties with the institute, and consider the past and future of the YSSP.

2017 Program
Participants | Biosketches and abstracts | Proceedings

2017 YSSP Awards

IIASA has instituted two annual awards for exceptional young scientists participating in the YSSP. The Peccei Award is awarded in recognition of rigorous research that makes a policy contribution, while the Mikhalevich Award is given to students who use mathematical tools to solve real-world questions. The recipients of these awards are allowed to return to IIASA for another three months.

Hana Mandova received the Peccei Award for her paper titled, "Optimization of European biomass resources for integrated steel plants". Mandová is a second-year PhD student at the University of Leeds, UK, and spent her YSSP summer in the Ecosystems Services and Management Program.

Yaoping Wang also received a Peccei Award for her paper titled "Hydroclimate impacts on current and planned coal-fired power plants in Asia". Wang is originally from China and is a PhD candidate at Ohio State University, USA. She spent her summer in the Energy Program.

Pablo Ortiz Partida received the Mikhalevich Award for his paper on "Robust management of multipurpose reservoirs under uncertainty". This work was a result of his time spent with the Water, Ecosystems Services and Management, and Advanced Systems Analysis programs over the summer. Originally from Mexico, Partida is a PhD candidate at the University of California, Davis, USA, under a scholarship from CONACYT (Mexico's Science and Technology Ministry).

Southern African Systems Analysis Centre

In 2016, the South African National Research Foundation and the country's Department of Science and Technology, in collaboration with IIASA, launched the Southern African Systems Analysis Centre (SASAC), with the aim of expanding systems analysis capacity in the region. The center is currently hosted by a consortium of four South African universities, namely the Universities of Limpopo, Stellenbosch, the Western Cape, and the Witwatersrand.

SASAC, which builds on the success of the Southern African Young Scientists Summer Program that ran from 2012 to 2015, provides a dedicated bursary program with annual calls for South African PhD students based at South African universities to pursue their studies with a supervisor experienced in systems analysis. The center also offers an annual capacity-enhancement program for South African and international postdoctoral researchers.

In 2017, 20 PhD students were awarded three-year bursaries, forming the second cohort of SASAC-supported PhD students. These students received six weeks of intensive training in systems analysis at two South African universities, and had the opportunity to visit IIASA for a week, to learn more about the institute and its research. In addition, 27 postdoctoral researchers from Cameroon, India, Iran, southern Africa, and Tanzania had the opportunity to attend a three-week capacity-enhancement program, which included presentations by IIASA researchers. The program comprised training units in advanced methodology, research skills, and scientific writing within a systems analysis framework.

Building systems analysis expertise

In 2017, IIASA scientists hosted or coordinated 98 events worldwide, including a number of workshops and activities designed to build capacity in systems analysis. Below is a small selection of these activities.

Workshops on Negative Emissions, Food Security, and the SDGs, IIASA

International Workshop on Atmospheric Modeling Research in East Asia, IIASA

Future of Eurasian and European Integration: Foresight–2040 Conference, IIASA

IIASA Workshop on Systems Analysis for the Arctic presented at the 3rd Pan-Eurasian Experiment (PEEX) Science Conference, Russia

Workshop on Demographic Analysis with Applications to Aging Societies, Thailand

Workshops on Modeling and Projecting Sub-national Population Trends, China

Workshop on Scientific Support to Pollution Management in the Hanoi Region, Vietnam

Climate action: Solutions for a changing planet (online course)

See all 2017 events

Map showing the diverse array of nationalities of IIASA postdocs and participants of the Young Scientist Summer Program. The interactive online version gives a full list of participants for each country.

Global

Selected highlights

Improving the resilience of systems

Meeting ambitious climate mitigation targets

Climate research needs a greater focus on human populations

Identifying development and climate vulnerability hotspots

In search of viable pathways for sustainable development

Improving projections of future land use and environmental impacts

GLOBAL, REGIONAL, NATIONAL

Improving the resilience of systems

Systemic risk describes the likelihood of cascading failures in networks. Such risks arise in a broad range of different systems, such as power grids, ecosystems, supply chains, financial networks, disease dynamics, and transportation networks. The Systemic Risk and Network Dynamics (SRND) cross-cutting project at IIASA, aims to develop capabilities for analyzing systemic risks and to demonstrate how to assess and mitigate risks of cascading failures.

While most existing approaches to systemic-risk assessment are application-specific, similarities between systems offer great potential for cross-fertilization and synergetic analyses. Specifically, the project is developing cross-cutting measures of systemic risk, prognostic tools for assessing the likelihood and extent of cascading collapses under uncertainty, methods for reducing systemic risk through network design and control, and new approaches to the governance of systemic risk.

The project explores systemic risk in a broad range of applications from natural to human-made systems. In 2017 for example, researchers working on the SRND project explored the effectiveness of credit default swaps (CDSs) as an alternative or complementary instrument to the systemic risk tax studied earlier [1]. Over recent years, CDSs have acquired a negative reputation, as they are widely used for speculations, which are seen as exacerbating financial systemic risk. However, using an economic-financial model, the results of one study [2] showed that, by properly shifting financial exposures from one institution to another, a CDS market can be designed to rewire the network of interbank exposures in ways that make it more resilient to insolvency cascades.

The project also developed and used an agent-based model (ABM) simulating a national economy previously developed by its researchers, to estimate the indirect economic consequences of direct losses arising from floods. This model is the first to use a 1:1 scale to represent a country's natural persons and legal entities, such as firms and banks, and to simulate their interactions. The ABM is currently calibrated for Austria, using data from national accounts, census data, and business information. It is driven by a probabilistic flood model, which uses the copula approach to predict flood losses while accounting for spatial dependencies. In this way, the researchers link environmental and economic processes in a nationwide simulation. Their analysis predicts that moderate floods induce positive indirect economic effects in the short and medium term, and small but negative indirect economic effects in the long term. In contrast, large-scale floods result in a more pronounced negative economic response in the long term. This approach allows the researchers to identify winners and losers in unprecedented detail across all economic sectors, as well as fiscal consequences for the government, both of which are crucial for managing extreme events resulting from climate change and natural disasters. A paper presenting these findings has been submitted for publication.

Furthermore, the project's work on systemic risks in ecosystems is ongoing. Researchers working in this thematic area analyze how species losses propagate through food webs. In particular, they have developed what has become the world's largest database of quantified food webs, and have used this information on ecosystems from around the globe to calibrate their models. This provides a unique basis for addressing controversies that have persisted in the ecological community for decades, concerning the question of which structural features make food webs more or less vulnerable to species loss. The researchers have expanded this resilience analysis from the ecosystem level to the species level.

Since its inception, the SRND project has been enabling the three participating IIASA programs to pool their methodological expertise on dynamic systems, risk analysis, and network theory. In light of this, a perspective paper is being prepared that presents an integrated approach using the copula methodology, for combining individual risks (in the form of probabilistic distributions) and systemic risks (in the form of copulas describing the dependencies among such distributions). This approach is especially useful when extreme events (occurring at low probabilities, but having high impacts) that affect agents in a system can lead to a tightening of the connections between some or all agents, as is often the case in, for example, financial systemic risks.

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- Risk and Resilience Program, IIASA
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- Department of Statistics and Operations Research, University of Vienna, Austria

Further information

- Systemic Risk and Network Dynamics

Meeting ambitious climate mitigation targets

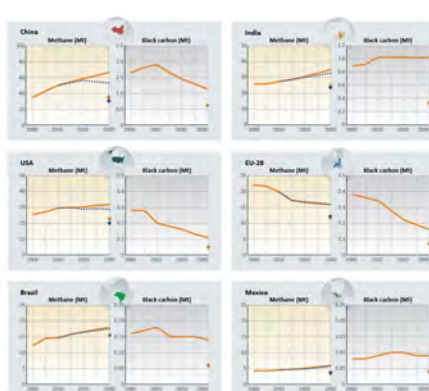Air Quality and Greenhouse Gases

Research shows that reducing the emissions of short-lived climate pollutants (SLCPs) will play an important role in meeting the 2°C target of the Paris Agreement. Although these emissions will be partially reduced as a consequence of carbon dioxide (CO2) mitigation, it will not be enough. According to the IIASA Air Quality and Greenhouse Gases (AIR) Program, additional, dedicated SLCP policies that will also deliver other benefits such as improved health will be needed.

Anthropogenic climate change is largely driven by human-induced changes in the composition of the atmosphere, including long-lived greenhouse gases that have lifetimes of approximately eight years or more, and SLCPs that have lifetimes of approximately 20 years or less. The challenge with SLCPs is that reducing their emissions may lead to undesired warming in the atmosphere. However, many SLCPs are also considered air pollutants that have negative effects on human health, crop productivity, and ecosystems.

The IIASA AIR program has been a forerunner in analyzing the role that SLCPs could play in meeting ambitious climate mitigation targets. In 2017, researchers concluded a number of important research projects in this field. These include an improved estimate of current and past emissions of black carbon (one of the notorious SLCPs) [1]; an analysis of how changing emissions of aerosol precursors have influenced the radiative balance of the planet in past decades [2]; an innovative analysis of the contribution of solid fuel cook stoves to the aerosol load in the atmosphere [3]; and an analysis of the interactions between SLCP mitigation and the sustainable development goals [4].

Led by Zbigniew Klimont and coauthored by Lena Hoglund-Isaaskson, both from IIASA, Chapter 6 of the 2017 UN Environment Program (UNEP) Gap report is dedicated to the role that SLCPs could play in achieving ambitious long-term global temperature targets. The team, which consisted largely of AIR program researchers and their current collaborators, highlighted that reductions in SLCPs are most effective when accompanied by reductions in CO2. Since CO2 and SLCPs often have the same sources, synergies can be reaped in reduction efforts. The researchers however caution that some pollutants are not co-emitted and need to be targeted individually. Moreover, because they have a shorter lifespan and thus influence the atmosphere in characteristically different ways, it is neither useful nor appropriate to translate SLCF mitigation to carbon-equivalent units. The authors recommend that long-lived greenhouse gases and SLCPs should be considered and targeted separately with policies tied to specific, non-convertible measures.

The UNEP report concludes that SLCF potential emission reductions are significant. It states that SLCP reductions will be an integral part of a strategy that aims to keep global temperature increases to less than 2°C, and that early reductions would not only help to slow the rate of climate change in the short term, but also provide substantial health benefits. In the

Regional baseline methane and black carbon [shaded background] emissions and mitigation potential by 2030 [Mt per year].

future, coreductions of SLCF because of CO2 reductions will play a role, but additional specific policies for SLCPs will be needed.

Over the past few years, the AIR program has also significantly extended and improved estimates of mitigation potentials and the costs of reducing SLCPs. This helps to better understand and design cost-effective strategies to reduce future climate change impacts in a complex world of interacting atmospheric processes and economic and environmental constraints.

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Further information

- Global emission fields of air pollutants and GHGs
- Impacts of Short-Lived Air Pollutants
- Benefits from Reducing Short-lived Climate Forcers

GLOBAL, REGIONAL, NATIONAL

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Climate research needs a greater focus on human populations

World Population

The way in which climate change will affect future populations will depend largely on people's capacity to adapt to changing conditions. According to IIASA researchers, such characteristics can be forecast in the long term using well-established demographic methods.

Climate research has provided a range of scenarios showing how climate change will affect global temperatures, water resources, agriculture, and many other areas. Yet it remains unclear how all these potential changes could affect future human wellbeing. In particular, the population of the future – in its composition, distribution, and characteristics – will not be the same as the population observed today. That means that assessing likely impacts by relating the climate change projected for the future to today's societal capabilities can be misleading. In order to understand the impacts of climate change on human beings, climate change research needs to explicitly consider forecasting human populations' capacities to adapt to a changing climate.

The demographic tools to do this are already available and well established. Global IIASA population and human capital scenarios up to the year 2100 include not just numbers of people, but also their distribution by age, sex, and education level. These scenarios form the human core of the Shared Socioeconomic Pathways (SSPs) that are widely used in research related to climate change.

In an article based on a growing body of research from IIASA and the Vienna Institute of Demography [1], which was published in the journal Nature Climate Change [2], IIASA researchers discuss a conceptual model that can account for the changing characteristics of populations through the replacement of generations, called "demographic metabolism."

Podcast: The focus on human populations in climate change research. Interview with IIASA researcher Raya Muttarak

The concept of demographic metabolism can be described as the process whereby individuals in a population are constantly replaced, just like cells turn over in a body. People of today differ in many ways from their parents and grandparents, and the same will hold true for future generations. They differ in education levels, in health, environmental awareness, and many other factors—and what the research has shown is that these factors directly affect a population's vulnerability to natural disasters or changes in the environment.

The researchers explain that some characteristics that people acquire early in life, like education, remain with them throughout their lives.

Research by the IIASA World Population Program has shown that education in particular influences how vulnerable people are to natural disasters like floods and storms, which are expected to increase as a result of climate change. With more educated younger generations replacing the older ones through the demographic metabolism process, it may be possible to anticipate a future society with higher adaptive capacity.

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Further information

- Forecasting Adaptive Capacity to Climate Change
- Climate research needs greater focus on human populations
- Education – Preparation for the unexpected

Identifying development and climate vulnerability hotspots

Large-scale initiatives

Understanding the interplay between multiple climate change risks and socioeconomic development is increasingly required to inform policies to manage these risks in pursuit of the sustainable development agenda. To this end, IIASA researchers working on the Integrated Solutions for Water, Energy, and Land (ISWEL) project conducted a comprehensive assessment of the potential exposure of global and vulnerable populations to multi-sectoral climate risk hotspots under different levels of global warming.

The 21st century will see the global population increase from 7.5 billion in 2017, to an expected 8.5-10 billion in 2050 [1]. Future populations will be exposed to a growing range of climate change hazards of varying intensities, with some areas–or hotspots–exposed to more risks than others [2]. These risks are not just dependent on the severity of climate change and subsequent hazards, but also hinges critically on the population's exposure, and their vulnerability and capacity to prepare for and manage changing risks. Recently, a few studies have brought attention to the fact that the world's poorest are disproportionately exposed to climate risks, such as changes in temperature extremes and challenging hydro-climatic complexity [3].

In order to inform effective, integrated policy responses to these problems, it is necessary to assess the exposure of future global and vulnerable populations to multi-sector climate impact hotspots. IIASA researchers working on the ISWEL project investigated where the main multi-sector risk hotspots are located globally, how they might change with higher levels of global mean temperature rise, and to what extent socioeconomic development and poverty reduction can reduce risks. The results of their assessments indicate that, although global exposure to multi-sector risks will affect a relatively small fraction of global land area, the risks to human populations will be large.

The general structure of the assessment comprised the development of 14 climate and development indicators across the water, energy, and land sectors, and the aggregation of impacts and risks using new and established methods to produce multi-sector risk hotspot maps. These maps were then compared for 1.5°C, 2.0°C, and 3.0°C changes in global mean temperature above pre-industrial conditions. The exposure of global and vulnerable populations (i.e., those with an income of less than US$10 per day) was also investigated using three socioeconomic projections from the Shared Socioeconomic Pathways (SSPs 1-3). The results of these assessments are presented at the global grid and Intergovernmental Panel on Climate Change (IPCC) region scales.

Looking to understand the differences between the temperature targets in the Paris Agreement, the researchers found that the differences between 1.5 and 2.0°C were considerably larger than expected. The increase in exposed population to multi-sector risks almost doubles from 1.5 to 2.0°C, and similarly doubles again at 3.0°C (from 1.5 to 2.7 to 4.6 billion). Both the scale of and the differences between these numbers underline the benefits of climate mitigation that will be experienced across the world, predominantly in developing regions.

For populations vulnerable to poverty, the importance of targeted poverty eradication to reduce vulnerability is clear. The differences between the SSP1 (sustainability–affluent, low inequality, high education) and the SSP3 (rocky road–development failures, high inequality, low education) socioeconomic pathways, potentially alters the number of exposed and vulnerable population by an order of magnitude. In all scenarios, the exposed and vulnerable population lie disproportionately in Asian and African regions (91-98%), with approximately half living in South Asia alone. As the most undeveloped region, Africa faces worse risks than most regions, especially in high inequality socioeconomic scenarios and high warming climate scenarios.

Climate mitigation alone will not be enough to reduce the exposure of the world's poorest, who will still be vulnerable to impacts at 1.5°C. According to the researchers, action to rapidly reduce inequality, eradicate poverty, and promote proactive adaptation through mechanisms such as the Sustainable Development Goals, would greatly reduce the size of exposed and vulnerable populations, especially if co-benefits for climate mitigation also accrue.

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- Global Environment Facility (GEF)
- United Nations Industrial Development Organization (UNIDO)

Further information

- Integrated Solutions for Water, Energy, and Land (ISWEL)

In search of viable pathways for sustainable development

The World in 2050 (TWI2050) is a global multi-year, multi-partner research initiative launched by IIASA with international partners that involves almost all research programs at the institute. The main focus of the initiative is on deriving viable pathways for achieving all 17 Sustainable Development Goals (SDGs) and to provide fact-based knowledge to support associated policy processes and implementation issues. The initiative achieved several important research milestones in 2017.

IIASA, together with the Sustainable Development Solutions Network, the Stockholm Resilience Center, and the Earth Institute at Columbia University, launched the TWI2050 initiative in the wake of the United Nations' 2030 Agenda that was agreed in New York in 2015. Using an integrated and systemic approach, TWI2050 aims to address the full spectrum of transformational challenges related to achieving all 17 SDGs. The objective is to provide the science and policy advice needed to achieve these goals in an integrated manner to avoid potential conflicts among the 17 goals and reap the benefits of potential synergies for achieving them together. TWI2050 brings together the leading modeling and analytical teams from around the world, including major policy institutions to analyze possible sustainable development pathways for a systems transformation that achieves the SDGs together, while staying within Planetary Boundaries in the long-term.

Under the leadership of Nebojsa Nakicenovic, IIASA Deputy Director and a researcher with the Transition to New Technologies (TNT) Program who also serves as Executive Director of TWI2050, important progress was made in 2017. The scientific framing of the TWI2050 initiative was completed and a draft paper on defining the SDG target spaces and associated indicators for 2030 and 2050 was completed. Both these papers, along with first drafts of corresponding SDG narratives, were presented and discussed at the third annual TWI2050 meeting, where the working groups also met to deliberate on their work plans around the major themes addressed by the initiative.

These activities are currently being integrated into a first TWI2050 report that will be presented to the UN High Level Political Forum in New York in July 2018. TWI2050 results related to technology policy were also presented to the UN Secretary General's Special Advisory Group on Technology Facilitation where Nakicenovic serves as a member. In addition to the above, the TWI2050 initiative developed a draft funding strategy and was actively involved with the Belmont Forum of Science Funding Agencies to prepare an SDG-related call for research proposals that is anticipated to become a major source of funding for TWI2050-related research globally.

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Further information

- Road maps and instruments for achieving the SDGs

Improving projections of future land use and environmental impacts

Earth's ecosystems are being pushed beyond safe limits in terms of freshwater use, biodiversity, and biogeochemical flows. According to researchers at the IIASA Ecosystem Services and Management Program (ESM), existing modeling tools need to be revisited to ensure that they are able to inform policies that can address this multi-faceted problem. To this end, ESM researchers refined the IIASA Global Biosphere Management Model (GLOBIOM) and started developing a flexible and scalable machine learning meta-model for the spatio-temporal downscaling of global crop model outputs.

As part of the Stimulating Innovation for Global monitoring of Agriculture (SIGMA) Horizon 2020 Project, ESM researchers embarked on a project to improve the cropland expansion and intensification process in the GLOBIOM agricultural and forest sector model. This included improving the downscaling functionality of the model to produce spatially explicit, reliable outputs on projected land-use change, and applying the model at the global scale to produce projections of cropland and major cropping systems for future scenarios in 2030 and 2050. In addition, the researchers developed methods to diagnose their impacts on greenhouse gas (GHG) emissions, reactive nitrogen flows, and terrestrial biodiversity.

As a first step, the ESM team improved the expansion and intensification modules of GLOBIOM. They collected new datasets to calibrate and set parameters for the new module functions, using a novel time series method to estimate crop and region specific price elasticities of area, quantity, and yield with a global coverage. Following this, they used the newly estimated elasticities to evaluate the behavior of the latest version of GLOBIOM. This diagnostic, along with additional data sources, and a novel global scale dataset of Environmental Policy Integrated Model (EPIC) crop model simulations (Hypercube), were used to improve the representation of cropland expansion and intensification in GLOBIOM. The team also used an econometric downscaling method for the land use and land use change results of GLOBIOM, where regional results are downscaled significantly. The method is capable of taking into account the uncertainty of existing land use maps, and provides valuable inference over the drivers of high-resolution land use change.
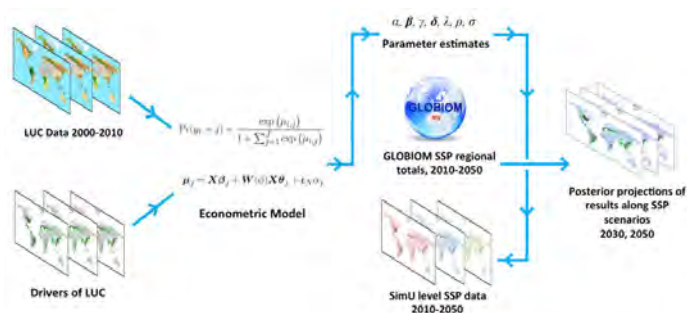

Overview of the GLOBIOM downscaling framework

Based on this new downscaling module, the researchers were able to provide cropland projections for 2030 and 2050 along different Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs).

To assess the environmental impacts of these high resolution land use changes, the team also developed novel methods to translate land cover and land use changes into habitat changes, species richness, and loss of threatened endemic species (in collaboration with ETH Zurich), by integrating a new dataset of estimates of scale water and nitrogen balances using the EPIC crop model. Preliminary results indicate, for example, that by 2050, significant intensification of cropland will increase the amplitude of nitrogen input to cropland and losses to the environment by more than 50%. Future changes in cropland extent will generate a moderate (less than 10%), but robust decrease in the average global species richness and loss of threatened endemic species richness. This implies that without mitigation efforts, the future expansion of cropland will generate additional GHG emissions. Future cropland extension could also amplify the effect of projected increase in cropland intensity in some scenarios, while increased climate change mitigation reduces cropland expansion and could lead to co-benefits for biodiversity.

Apart from the refinement of GLOBIOM, the Agro-Environmental Systems team at ESM also started developing a flexible and resource-efficient machine learning (ML) meta-model that would allow for spatio-temporal downscaling of crop model outputs at a high spatial resolution.

The IIASA-EPIC global gridded crop modeling (GGCM) framework, produces outputs at spatial resolutions that are often too comprehensive for use in regional and local decision making. The EPIC Hypercube dataset for example, provides monthly to annual data on global crop production, crop intensification responses, and associated environmental externalities. In 2017, in a collaboration with the International Maize and Wheat Improvement Center (CIMMYT), the team implemented a number of ML algorithms, namely gradient boosting and random forests, to downscale global EPIC Hypercube simulations of maize yield potential to a finer resolution at the extent of Mexico (project ColClim).

The ML model was tested for downscaling selected agricultural externalities, in addition to crop yields. Since additional data dimensions and environmental predictors are needed for developing a flexible ML meta-model, the team collaborates with the existing GGCM community and its ongoing activities, including the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP), to facilitate this requirement [1][2]. The

Examples of rain-fed maize yields for the year 2000 from (a) global IIASA-EPIC Hypercube at 0.5×0.5 arc-deg, and (b) corresponding ML predictions for Mexico at 1×1 km.

ML meta-model provides the means to inform decision-making processes at regional and sub-regional scales

These methodological improvements allow comprehensive quantitative assessments of future land use change and related policies, and will increase the ability of researchers to cooperate both within and outside of IIASA. This work was presented at conferences [3][4] and has led to several publications [5][6][7]. It is also currently contributing to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) process and generating new scenarios, which are expected to lead to high policy impact in 2018.

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Further information

- SIGMA
- GLOBIOM
- EPIC
- Agro-Environmental Systems (AES) Group

Africa

Selected highlights

Ecological network analysis reveals systemic impact of threats to ecosystems

Exploring sustainable biofuel feedstock potential in Sub-Saharan Africa

Informing sustainable water management options

Solutions for a water secure East Africa in 2050

GLOBAL, REGIONAL, NATIONAL

Member countries

Egypt   South Africa

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Ecological network analysis reveals systemic impact of threats to ecosystems

Advanced Systems Analysis

Ecological network analysis provides a systematic approach to assess the direct and indirect influences that one network node has on another. Researchers from the IIASA Advanced Systems Analysis Program engage in projects to develop these methodologies further and to explore new applications.

As part of the Southern African Young Scientists Summer Program (SA-YSSP), IIASA researchers conducted systems analysis on a food web ecosystem in an estuary near Durban, South Africa [1]. The food web was analyzed using a novel methodology to identify keystone species (i.e., organisms that play a unique and crucial role in the way an ecosystem functions). The importance of a species was measured by the degree to which it influences other species or functional groups. While other keystone measures focus on the overall influence, this method differs because of a biomass-normalization that removes the bias of larger biomass compartments (i.e., the total quantity or weight of organisms in a given area) such as phytoplankton and detritus. This approach highlights the ecosystem interactions of smaller, typically top predator species. The results revealed that several predatory fish groups exhibited strong top-down control on the ecosystem. The research also utilized a unique time series dataset that allowed for investigation of changes in the food web during different seasons and different hydrological conditions. The study concluded that the ecosystem, in terms of the keystone species, remained resistant to these changes and other imposed disturbances.

Another network project undertaken during the Young Scientists Summer Program, and subsequently awarded the Peccei Award, employed a novel "networks of networks" approach that utilized both social and ecological network data [2]. A series of 19 reservoirs in Nebraska, USA, were studied to determine the spread of an invasive snail species. Food webs for each of the reservoirs were constructed based on collected field data. The invasive species were identified in five reservoirs. These reservoirs were considered contagious, as it was known that the snails could be spread to other reservoirs by anglers. Social network data showed how anglers moved from one reservoir to another based on their fishing preferences–where they had last fished and where they intended to fish next. The snails attach themselves to boats and in this way have a chance of being transported to other reservoirs. Hence, researchers considered the uninfected reservoirs susceptible to invasion. Once the species were introduced to a new reservoir by anglers moving between the different bodies of water, the reservoir was "infected" and the food web model in that reservoir would change as a result of the invaders' feeding patterns. At some point, the snail population in the newly infected reservoir would

grow large enough to be contagious and the contamination process would be repeated. This network of networks approach identified which reservoirs are critical to avoid outward spread and inward infection, in order to slow the presence of the invasive species.

In a third study, an ecological network approach was used as the foundation for understanding system sustainability [3]. All systems are open thermodynamic systems, in other words, they freely exchange energy and matter with their surroundings. This means that how they organize to use this energy is key to their sustainability. The IIASA researchers found that networks that maximize the total flow of energy or matter through the system and the time that energy/material stays in a particular compartment of the system via cycling, are also the ones that can best slow down energy dissipation and thus achieve greater levels of energy extracted from available resources. According to this study, structural-, and functional organization that follows this pattern is observed in ecosystems and may prove to be a useful template for designing human, socioeconomic systems.

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Further information

- Young Scientists Summer Program (YSSP)
- Southern African Young Scientists Summer Program (SA-YSSP)

Exploring sustainable biofuel feedstock potential in Sub-Saharan Africa

The Worldwide Fund for Nature South Africa (WWF-SA) has commissioned IIASA to assess pathways towards large-scale, sustainable aviation biofuel deployment in Sub-Saharan Africa, and to address the complex interlinkages in different dimensions of the agriculture-energy-environment system.

The International Civil Aviation Organization has adopted the goal of carbon neutral growth from 2020 onwards (IATA, 2013). Large-scale aviation biofuels, including diverse agricultural feedstocks (i.e., raw materials), are anticipated to play a key role in achieving the target in the longer term.

Biofuels are produced from a range of diverse biomass types, including plant materials, vegetable oils, and starch. As biomass is a limited resource, the aviation sector will add to demand from food, feed, and other non-food agricultural products. To this end, the aviation industry called on the WWF-SA to embed and discuss the development of biomass for energy into a broader perspective of agricultural and socioeconomic development in Sub-Saharan Africa. The region is seen as one of the major expansion areas for the production of biofuel feedstocks.

The guiding principles used for the sustainability assessment were those developed by the Roundtable on Sustainable Biomaterials (RSB), an independent and global multi-stakeholder coalition. The IIASA ecological-economic modeling framework, which comprises the Food and Agriculture Organization of the United Nations (FAO)/IIASA Global Agro-ecological Zones and the IIASA World Food System model, was used to implement the RSB principles on food security, greenhouse gas (GHG) emission saving, environmental conservation, soils, and water management. The researchers defined exclusion layers such as food crops, livestock, safeguard areas of high value for biodiversity and the environment, and quantified them. This revealed some 'unprotected' grass- and shrubland areas that are potentially available for biofuel feedstock production. In addition to current land balances, development scenarios until 2050 evaluated future geospatial patterns of food production and associated land demand.

Once food security and environmental sustainability criteria were accounted for, the balance of remaining land (REMAIN land) was explored for its suitability and capacity to produce a variety of biofuel feedstocks, and assessed in relation to the GHG emissions saving criteria. The assessment included 11 feedstocks ranging from extensively employed, well established conversion pathways (e.g., sugar cane and cereals to bioethanol, or diverse vegetable oil crops to biodiesel) to novel crops (e.g., vegetable oil from solaris tobacco), and second-generation lignocellulosic biomass (i.e., all biomass that has a relatively high content of lignin and cellulose). This has been, and is still being extensively explored in a number of research and demonstration projects (e.g. miscanthus silvergrass).

The results of the study [1] indicate that about one third of REMAIN land, or 1.9 million km2 are agro-ecologically very suitable, or suitable for the production of some annual or perennial biofuel feedstocks. However, exploitation of these land resources will require land conversion from natural shrub- and grasslands to cropland, followed by intensive feedstock cultivation practices. This will in turn result in substantial initial carbon debts due to the removal of the existing vegetation and the partial loss of soil carbon. The sustainability GHG emissions saving criteria set by the RSB requires at minimum a 60% saving relative to the fossil fuel comparator when using a 20-year accounting period. Adhering to this criterion implies that primarily perennial biofuel feedstocks requiring less frequent and less intensive cultivation of soils, can meet the criteria when conversion of natural grassland or shrubland is involved.

The sustainable production potential on prime land quality is restricted to miscanthus (silvergrass), palm oil, and sugarcane, and amounts to a current energy potential of some 6,000 petajoules. Over time, available REMAIN land shrinks because of additional cropland required for food production, which is projected to halve the current sustainable biofuel potential to about 3,000 petajoules by the 2050s. According to the results, annual feedstocks such as sweet sorghum would only be eligible under a less strict GHG criterion that uses a 60% GHG emission saving applied to the biofuel life cycle emissions in each year, and requires a payback period for additional emissions from direct land use change of less than ten years. In such a case, the current potential would increase to 12 thousand petajoules (biofuel equivalent).

In addition to the above, agricultural residues from food production could provide additional biomass for fuel production. When applied to 2010 data, the model shows that allowing 2 tons of crop residues per hectare to remain on the field to comply with the RSB principle on safeguarding soil fertility, results in a useable crop residue potential of 97 million tons (equivalent to 617 petajoules), thus increasing the potential from REMAIN land by 10%. Unlike REMAIN land, which will be decreasing towards the 2050's, cultivated land for food production and associated crop residues will be increasing.

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Further information

- Sustainable aviation biofuel supply chains
- Global Agro-ecological Zones (GAEZ)
- World Food System model (WFS)

Informing sustainable water management options

Water

Pressure on the world's water resources has been mounting substantially in recent decades, and is expected to be further exacerbated by climatic and socioeconomic changes in the future. The Extended Continental-scale Hydro-economic Optimization Model (ECHO) developed by the IIASA Water Program is a useful tool for assessing the economic and environmental impacts of water scarcity and evaluating the effectiveness of management options.

Global water extractions have been increasing rapidly over the last decades to support growing food and energy needs, and increasing standards of living [1]. As a result, many basins around the world have experienced pervasive water scarcity conditions and related water management challenges [2]. These challenges are expected to become even more critical in the coming decades, as countries attempt to sustain a larger and more prosperous human population and economy under changing climatic conditions [3]. As such, policymakers in vulnerable regions need to anticipate how to adapt management practices to secure reliable future water supply that can meet the demands of different sectors. In recent decades, hydro-economic models have emerged as an important tool for informing the design of efficient and sustainable water management options, because they typically feature an integrated biophysical-technological-economic representation of water resource systems [4].

Although hydro-economic models are typically designed at basin scale, with a few designed to model systems ranging in size from household or utility level, to transboundary basin scale, they are rarely used across larger spatial scales. This provides an opportunity to integrate a detailed representation of local biophysical (e.g., available water resources) and technological (e.g., infrastructure) constraints with farther-reaching regional and global policies. This feature is particularly relevant, because the availability of water, energy, and land resources varies significantly at local scales, whereas the linkage to regional and international markets for energy and food commodities, along with transboundary treaties for water resources, have global influences [5]. The few existing large-scale hydro-economic models use a reduced number of spatial units (i.e., location-specific attributes) to minimize the computational burden, which limits their potential for integrating constraints at a local-level. In addition, most of these models only include a limited set of water management options, and many omit the implications of future management decisions in the energy and agricultural sectors.

To overcome these limitations, researchers from the Water Program developed the Extended Continental-scale Hydro-economic Optimization (ECHO) model to support the design of efficient and sustainable water management options. ECHO includes an economic objective function, as well as simplified representations of essential biophysical and technological features at sub-basin level within river basins at a continental scale. These include representations of various water supply sources (surface water, groundwater, and non-conventional water, such as desalinated water), sectoral demands (irrigation, domestic,

manufacturing, and electricity), and infrastructure (surface water reservoirs, desalination plants, wastewater treatment plants, irrigation systems, and hydropower plants).

Echo model output, showing total water demand, actual sectoral water withdrawals, and water sources in Africa, for various future socioeconomic and climatic scenarios towards 2050.
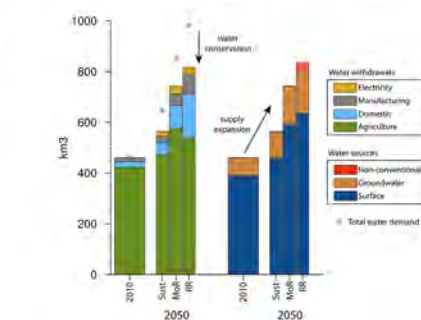
The objective function of ECHO minimizes the total costs of a wide variety of water management options over a long-term planning horizon (a decade or more), to satisfy sectoral water demands across the sub-basins. Management options include both supply and demand options that span over the water, energy, and agricultural systems.

ECHO has already been applied to Africa as a case study, in order to assess important interactions between the region's future water demands and availability under various future socioeconomic and climatic scenarios. The model is designed to operate at different spatial scales and in different regions or continents, subject to the availability of data.

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Collaborators

- The development of the ECHO model, which involves the IIASA Water and Energy programs, is carried out as part of the larger *Integrated Solutions for Water, Energy, and Land project*.

Further information

- Global Hydro-economic Model
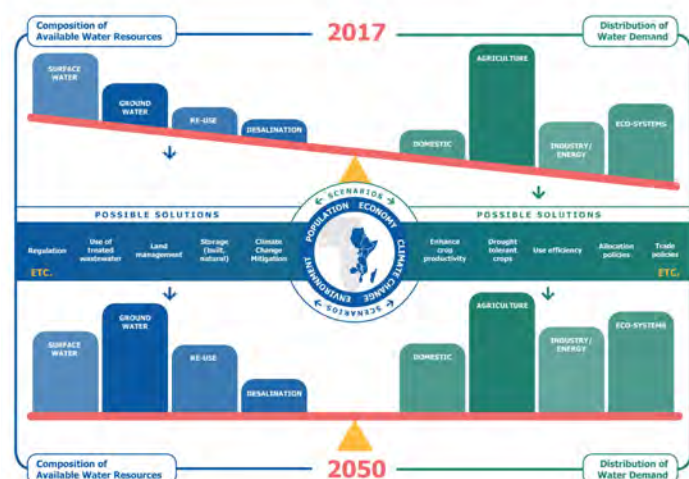- Integrated Solutions for Water, Energy, and Land (ISWEL)

Solutions for a water secure East Africa in 2050

The IIASA Water Futures and Solutions Initiative seeks to incorporate science into water policy and planning, and applied water management issues. Set up as an interdisciplinary scientific initiative, the project identifies and tests solution pathways across different economic sectors, including agriculture, energy, and industry, while safeguarding the environment.

The Water Futures and Solutions Initiative engages with stakeholders from across the globe to support and codesign future development scenarios and possible options for the management of water resources. It provides important input that support mid- to long-term water management and planning based on informed decision making. After a global analysis undertaken in a first fast-track assessment, the initiative is now focusing on Eastern Africa with the Lake Victoria basin as a key research area. With funding from the Austrian Development Agency, the Water Futures and Solutions Initiative formed an East Africa node. This corresponds with one of the priority regions of Austria's development cooperation policy.

Key actors of the Lake Victoria basin like the Lake Victoria Basin Commission and its member countries, the Nile Basin Initiative, and the Global Water Partnership, among others, expressed interest to engage in mutual learning and participate in model development and the co-creation of scenarios of future water demand and regional water management options. Regional stakeholders worked with a team of four IIASA staff members to identify priorities, development pathways, and potential for investments and solutions. In light of the above, Uganda in collaboration with IIASA, co-hosted a three-day workshop in Entebbe, Uganda, on the issue of projecting future water demand and water availability in the Lake Victoria basin.

The workshop, which took place in December 2017, attracted more than 50 practitioners engaged in government, academia, business, and civil society in the East African community, to discuss mid- to long-term water resource management options towards 2050. For many of the participants, the workshop presented a first opportunity to discuss systems thinking approaches aimed at understanding future development scenarios and their implications for water management practices.

Each workshop day had a particular focus with highly interactive and engaging discussions triggered by participatory facilitation techniques. The discussions on the opening day revealed a number of key challenges and opportunities concerning the use of modeling to support informed water resource planning decisions. One full day was dedicated to gaining a deeper understanding of development scenarios resulting from the East African community's vision for 2050. Discussions focused on how water can support development aspirations as an enabler, and how water resources are likely to be adversely affected as a result thereof. The final day of the workshop saw participants building partnerships on boosting modeling and scenario building capacities in the region. This will likely form the basis of future research collaborations and work packages, which will either be implemented in the coming year, or developed into funding proposals.

To this effect, a joint funding proposal involving interested partners from East African academic institutions, which was collaboratively developed between the Lake Victoria Basin Commission, Uganda and IIASA, will be elaborated and submitted to a range of development partners already engaged in transboundary water management issues in the region. This could be of significant interest to a range of other IIASA member countries apart from Austria, who have similar priorities and interests.

GLOBAL, REGIONAL, NATIONAL

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Further information

- Solutions for a Water Secure East Africa
- WFaS: Fast-Track Analysis
- Water Futures and Solutions Initative

Americas

Selected highlights

Getting to grips with evolutionary fisheries science

Transforming agriculture in Mexico

Finding the perfect balance

Oil production releases more methane than previously thought

Member countries

Brazil   Mexico   USA

Getting to grips with evolutionary fisheries science

The IIASA Evolution and Ecology Program has played an internationally leading role in bringing attention to the evolutionary consequences of exploiting the world's fish stocks. Fishing not only affects the numbers of fish, but also their heritable characteristics. While most examples of such evolutionary changes concern shifts in how long organisms wait before starting to reproduce, a new study on Atlantic cod shows that evolutionary responses to fishing also affect other aspects of reproductive behavior.
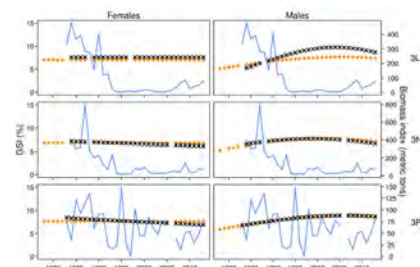
Fishing is an important source of food and nutrition for many people around the globe, especially in the developing world. Naturally, fish see only the other side of that coin—elevated mortality. It is widely acknowledged that even sustainable fishing practices inevitably reduce the abundance of fish populations. Until recently, an appreciation that fishing, when sustained over many generations, also affects the inherited characteristics of fish, was largely absent and is still developing. The Evolution and Ecology Program at IIASA has been assembling empirical evidence and developing the theoretical understanding required for finding the best ways to minimize unwanted evolutionary changes.

A very effective adaptation of fish to high fishing pressures is earlier maturation and the bulk of empirical evidence on the evolutionary effects of fishing confirms this. However, other traits are also likely to be important and the predominance of studies on maturation may in fact have more to do with the scarcity of data on evolutionary responses in other traits [1].

In the waters around Newfoundland in eastern Canada, fishing Atlantic cod has been the lifeline of local communities for centuries. The Department of Fisheries and Oceans (DFO) Canada has been conducting regular surveys on cod stocks since the mid-1980s, providing data to understand how cod populations have been developing. These data, on which the Evolution and Ecology Program have now collaboratively built with DFO scientists, allow researchers to study changes in the life-history characteristics of these stocks.

The cod stocks off Newfoundland are infamous for the collapse that led to the closing of cod fisheries in 1992, with full recovery from this disaster still pending. During the period leading up to the collapse, the size at which cod matured was gradually declining. Previous studies have shown that this decline was likely an evolutionary response to continued heavy fishing, as well as an indication of dangerously high fishing pressure, which could have served as a warning signal of the forthcoming collapse, had these analyses been available then [2]. Similar changes have been documented in numerous other cod stocks [1].

According to evolutionary theory, it is often advantageous for fish to invest more into their current round of reproduction if their chances of surviving to spawn again later are slim. This means that one might expect to observe larger reproductive organs (gonads) in the affected species. Fortunately, the DFO scientists measured the weights of gonads across large numbers of specimens, which offered a rare opportunity to test this theory [3].

Trends in relative gonad size of females (left column) and males (right column) for three stocks of Atlantic cod off Newfoundland (labeled 3L, 3NO, and 3Ps). In each panel, the blue curves show the estimated stock biomasses (right vertical axes). The two other curves show the model-predicted time trends of reproductive investments (measured by the gonadosomatic index GSI, that is, the ratio of gonad weight and gutted weight; left vertical axes) for the best models describing the data for the full time series (orange diamonds), or for the shorter period for which stock-biomass estimates are available (black crosses).

The researchers found that male cod met their prediction: their relative gonad weights were increasing during the period when fishing pressure was high. Moreover, these trends levelled off, or even reversed after fishing moratoria reduced fishing pressure, which is the predicted pattern if fishing was indeed the driving force behind these changes. However, an analogous pattern is not evident in female cod: their gonad weights were stable or even slightly declining, despite the theoretical predictions. The researchers found this even more surprising, given that gonad weight is commonly considered more important for the reproductive success of female cod than of male cod [3].

The reasons for the differences in the results for male and female cod are not yet properly understood. A possible explanation is the higher temporal variability in female gonad weights during the spawning seasons, making them a rather imprecise measure of the underlying energetic investments into reproduction. In addition, the results suggest that sperm production is more important for the reproductive success of male cod than previously appreciated.

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Further information

- Evolutionarily Sustainable Consumption

GLOBAL, REGIONAL, NATIONAL

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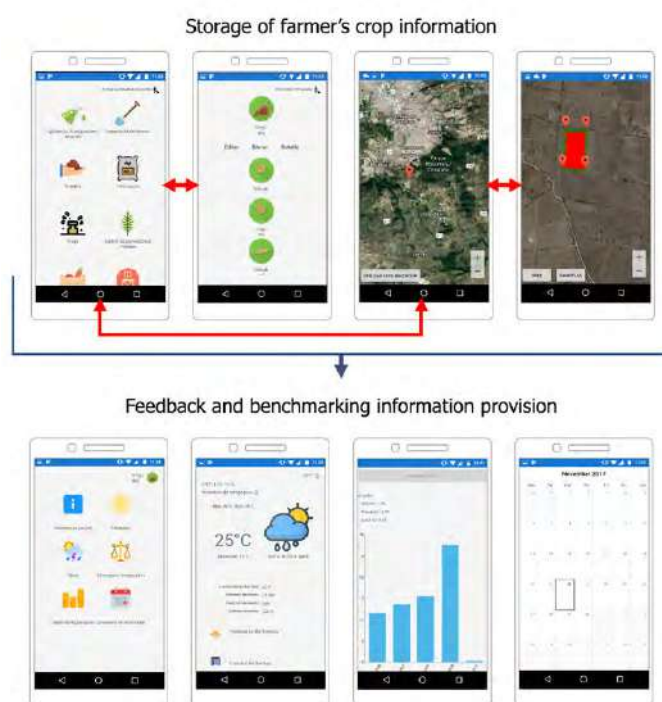
Transforming agriculture in Mexico

A freely available mobile application developed by IIASA researchers in collaboration with the International Maize and Wheat Improvement Center (known by its Spanish acronym CIMMYT), is providing farmers in Mexico with tutorials and expert advice to improve their farming practices and crop yields.

The Agrotutor application is an output of the Ecosystem Services and Management Program's Technological Portfolios and Modeling Techniques for Sustainable Intensification Project. The current version of the application allows farmers to create a user profile and register land parcels and the crops grown on them at different periods throughout the season. The app then provides the farmer with timely agronomical recommendations, potential yield, and financial benchmarking information, as well as historical and forecasted weather data.

The application uses the mobile phone's global positioning system (GPS) to geo-reference the registered land parcel, and gives the farmer access to very high-resolution Google satellite imagery of the land parcel in question. The farmer can delineate the parcels and introduce basic information such as the crop and cultivar planted (including maturity type and ideal climate), and the planting date. It is also possible to record CIMMYT-promoted parcel technologies and all agronomical activities performed, such as fertilization, irrigation, and pest management, as well as additional detail on these activities including costs, products used, and dosages applied.

Once the basic information and geo-location of a land parcel have been registered, the application provides crop and location-specific information representing large data sets and calculations in a simplified way. This includes the outputs of the IIASA Environmental Policy Integrated Climate (EPIC) crop model, which show potential performance (yield) for five different years for irrigated and non-irrigated areas. Based on extensive CIMMYT ground data, anonymous benchmarking information regarding costs, income, utility, and performance (yield), as well as current, forecasted, and historical weather information, are also included. In addition to these outputs, a series of windows of opportunity are shown in calendar format, where the application suggests optimal periods to execute agronomical activities (e.g., fertilization) on the selected parcels by taking into account growing degree days (from planting date onwards), as well as selected maturity and ideal climate for the specified cultivar. Farmers can also access links to tailor made materials previously developed by CIMMYT, such as tutorials for best agronomical practices.

Since the application was built in a modular way, future possibilities for expansion include delivering a larger variety of data such as market and financial information with the ultimate goal being to eventually provide farmers with a full Decision Support System. Such a system would use crowdsourced information obtained through the mobile application, which

CIMMYT IIASA Agrotutor mobile application.

could then be combined with data from price and market forecast models. These models (currently running at IIASA) would in turn give the farmer predicted buying/selling information for a given period or season. By coupling such forecasting systems with machine learning, crop modeling could enhance the results even further, thus simultaneously providing farmers with accurate and reliable technical and financial information. These additional features will be explored during the second phase of the project in 2018.

Further information

- Crowdsourcing Farmers' Data

Finding the perfect balance

Water

In many basins across the globe, increasing competition for water resources that serve multiple users in a variety of sectors, along with uncertain climatic conditions, are forcing decision makers to rethink the way in which multipurpose water storage facilities are managed. The IIASA Water Program has developed a novel optimization model aimed at improving reservoir operation in the transboundary Rio Grande basin. This model will enable resource managers to robustly, efficiently, and sustainably, allocate water among multiple users.

As the name implies, multipurpose reservoirs are constructed and equipped to provide storage and release of water for multiple purposes such as flood control, power development, irrigation, recreation, and domestic water supply. The management of these facilities often involve complementary objectives, but also conflicting goals [1]. An objective that has to do with supplying water for use in agriculture for example, would require having the water elevation close to its maximum storage capacity to increase water supply reliability. Conversely, flood management objectives would advocate for an empty reservoir with capacity to manage high, possibly catastrophic, inflows to reduce the risk of overtopping. Integrating water supply for environmental restoration as an additional objective may create even more competition. Different stakeholder groups typically pursue one objective over another, which leads to problems on how to minimize trade-offs among competing water management objectives in the presence of various uncertainties [2].
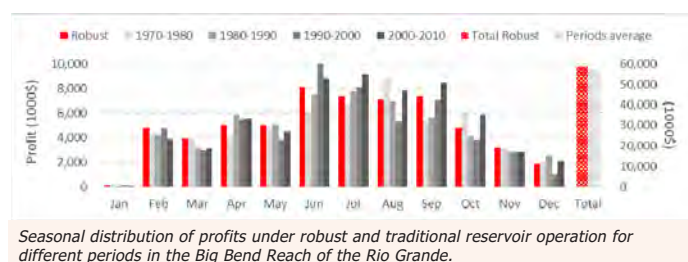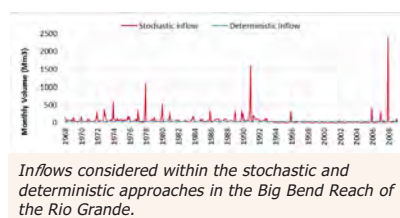
The trade-offs between competing objectives are traditionally managed by reservoir operation rules that dictate the range of water levels in the reservoir at the end of each month. The water level of the reservoir is directly related to its storage capacity, and therefore also to how much water it is able to supply to users. Traditionally, deterministic optimization methods are used to determine the optimal reservoir operation rules. This means that certain variables in real-life systems, such as inflows to the reservoir, water demands, or system losses, become parameters within the model (i.e., average inflow) [3]. Consequently, deterministic optimization models may fail to include the impacts of low probability, but high cost events such as floods or droughts. A major limitation of the deterministic approach is the consideration of a single set of streamflow, that is, the amount of water flowing in a river [4]. In reality, river systems may have high variability over different years, and a deterministic approach is not able to implicitly incorporate extreme floods or droughts in the optimization process.

While working with researchers from the Water Program as a participant of the 2017 IIASA Young Scientists Summer Program, Jose Pablo Ortiz-Partida developed a novel dynamic stochastic optimization model to address this problem [5]. The new model aims to improve reservoir management under uncertain climatic conditions and competition among many water-dependent systems, including water supply for off-stream uses, environmental requirements for healthy ecosystems, downstream delivery commitments, and flood protection. It maximizes regional economic benefits as a function of reservoir deliveries and integrates stochastic inflows into a water allocation system with different users, and physical and institutional constraints. The model derives robust reservoir operation rules that perform well under a wide range of uncertain climatic conditions.

Inflows considered within the stochastic and deterministic approaches in the Big Bend Reach of the Rio Grande.

The new model was applied to the case of the Big Bend Reach of the Rio Grande–a transboundary river basin of high importance for the United States and Mexico–in order to guide the risk-informed design of efficient and sustainable reservoir operation policies. The results suggest that the operation of the considered reservoir can be enhanced in such a way that higher economic benefits can be achieved in both the United States and Mexico, even while increasing environmental water allocation. The study expands global research on optimizing reservoir operations and has the potential to change current thinking where human and environmental objectives are mutually exclusive.

Seasonal distribution of profits under robust and traditional reservoir operation for different periods in the Big Bend Reach of the Rio Grande.

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Further information

- Transboundary Water Resources

Oil production releases more methane than previously thought

Air Quality and Greenhouse Gases

A new study from the IIASA Air Quality and Greenhouse Gases Program, which for the first time takes into account different production management systems and geological conditions around the world, shows that global methane and ethane emissions from oil production between 1980 and 2012 were far higher than previously thought.

Methane is a potent greenhouse gas, which scientists rank as the second-most important contributor to climate change after CO2. Yet, while methane concentrations in the atmosphere can be easily measured, it is difficult to determine the contribution of different sources, whether human or natural. This information is necessary for reducing emissions.
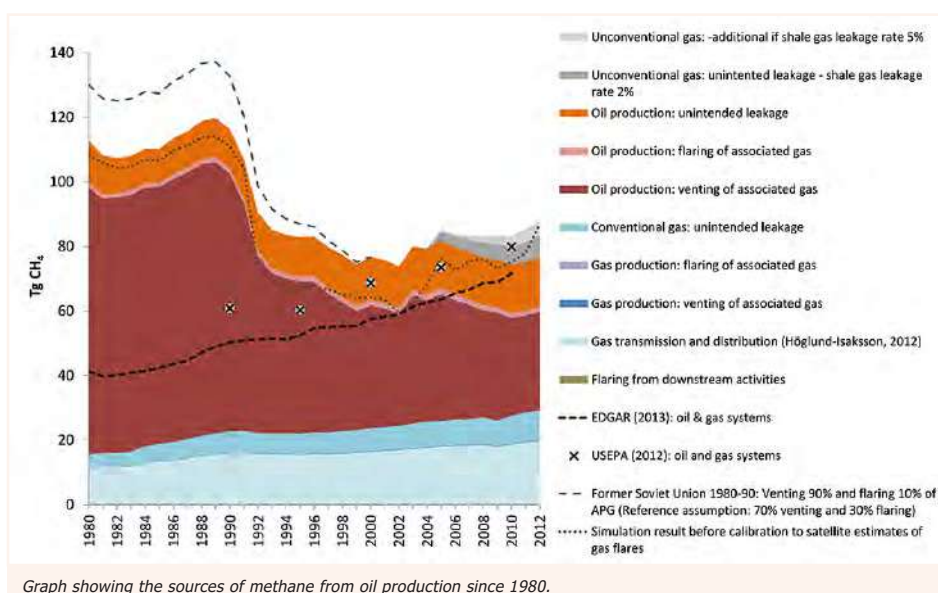
The layer of gas that is present above the oil in an oil reservoir, has a methane content of 50 to 85%. When the oil is pumped to the surface, this gas also escapes. In oil production facilities in North America, almost all of this gas is recovered and the portion that is not is mostly flared to prevent leakage and potential explosions, while a very small fraction is simply vented. In other parts of the world where recovery rates are lower, much larger quantities of this gas are released into the atmosphere.

Previous global bottom-up emission inventories of methane used rather simplistic approaches for estimating methane from oil production, merely taking the few direct measurements that exist from North American oil fields and scaling them with oil production worldwide. This approach however, leaves considerable room for error, which prompted an IIASA researcher to develop a new method that could better account for the many variations in oil production around the world.

In a paper on this work that was published in the journal Environmental Research Letters [1], global methane emissions from oil and gas systems in over 100 countries were estimated over a 32-year period. A variety of country-specific data was used, ranging from reported volumes of associated gas to satellite imagery that can show flaring, as well as atmospheric measurements of ethane, a gas which is released along with methane and easier to link more directly to oil and gas activities.

The study found that, especially in the 1980s, global methane emissions were as much as double the amount previously estimated. The results also show that the Russian oil industry contributes a large amount

to global methane emissions. A decline in the Russian oil industry in the 1990s contributed to a global decline in methane emissions, which continued until the early 2000's. At the same time, methane recovery systems were becoming more common and helping to reduce emissions. Yet, since 2005, emissions from oil and gas systems have remained fairly constant, which according to the research, is likely linked to increasing shale gas production

Graph showing the sources of methane from oil production since 1980.

that largely offsets emission reductions from increased gas recovery.

The study points out that these estimates are only as good as the data allow and that there is still uncertainty in the numbers. To improve the data, a close collaboration between the scientific measurement community and the oil and gas industry would be needed to make more direct measurements available from different parts of the world.

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Further information

- Oil production releases more methane than previously thought
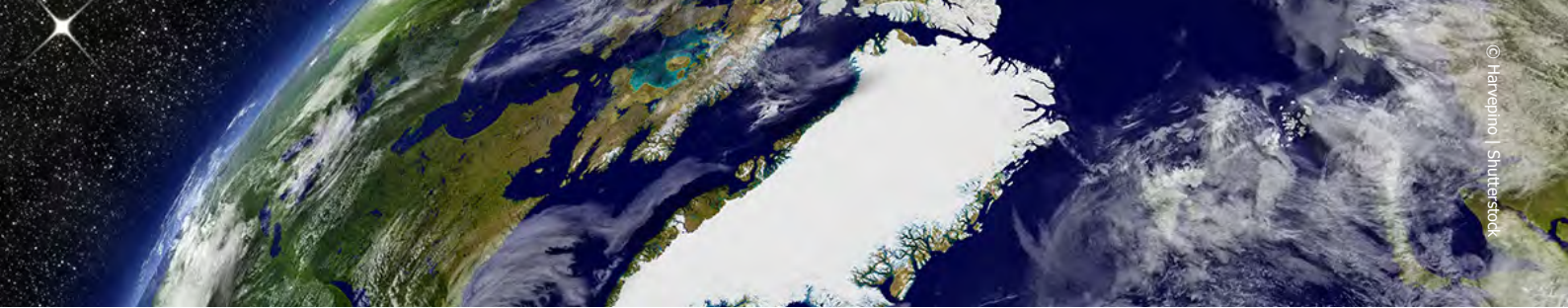
Arctic

The future of Arctic populations

The future of Arctic populations

Only 10 million people live in the vast 20 million square kilometer territory surrounding the North Pole. This relatively small number of local people, are however one of the driving forces in active Arctic transformation. The IIASA Arctic Futures Initiative explored what the Arctic population might look like in the future by applying an innovative projection methodology that factors in level of education.

Coverage of the Arctic area

The Arctic region covers more than 10% of the planet's total land area, but is one of the most desolate and least populated areas on earth because of its isolated location and harsh climate. Due to rapid and extensive changes in the region, people and places in the north are facing challenges to their livelihoods, environment, and culture. Climate change, industrial extraction, pollution, globalization, migration, and food- and water insecurity, along with widening socioeconomic gaps in the region, are not only affecting Arctic residents, but also have global consequences. Understanding the population dynamics and human capital associated with these changes will be crucial to finding solutions and addressing problems in the future.

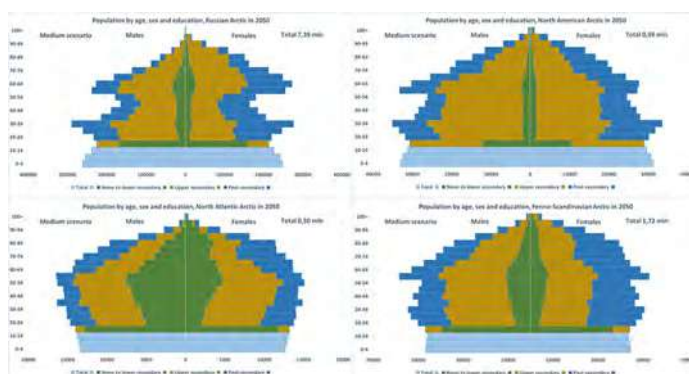In 2017, an IIASA study examined recent population developments in the Arctic and modeled future demographic trends towards 2050 [1]. To account for regional characteristics, the researcher incorporated assumptions on the processes of population change that are explicitly Arctic in nature in addition to global patterns. The age and sex parameters of interest, as well as the level of higher education based on the fertility and mortality of people with different education levels, were also explored.

This was done by applying three alternative scenarios for the future, which the researcher termed "medium development", "arctic boost", and "arctic dip" respectively. The medium development scenario projects a continuation of Arctic trends in the recent past, while the other two consider migration as a larger cause of demographic change. The arctic boost scenario implies a multi-faceted boom in the region based on an increase in the number of migrants, changes in climatic conditions, and technological developments. It also implicates faster education progression between educational levels, as well as an increase in the number of people with the highest qualifications who contribute to the boost. The arctic dip scenario in turn, entails accelerating out-migration as a driver of future

population decline, combined with a number of larger constraints to development in the Arctic. In this scenario, the progression of population groups to higher levels of education is much slower or even halted for the highest educational levels, as many qualified students/professionals may decide to pursue further education and careers elsewhere.

Total population of the Arctic by its four major constituting regions, 2050, Medium scenario

The resultant population projections suggest how education as a factor of human capital may drive demographic shifts in northern parts of Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the US. The innovative approach of projecting the population by level of education has not previously been applied to studies on the Arctic. Several communities have already expressed interest in the results, which could provide value input for stakeholders on decisions concerning the future development of this highly vulnerable and complex region.

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Further information

- Peace Symposium
- International Congress on Arctic Social Sciences

GLOBAL, REGIONAL, NATIONAL

Asia

Selected highlights

Asia's looming water crisis

In search of perfect foresight

Modeling sustainable transport options

Developing an open source energy model

GLOBAL, REGIONAL, NATIONAL

Member countries

China | India (Observer) | Indonesia | Iran | Israel | Japan | Korea | Malaysia

Pakistan (Observer) | Vietnam

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Asia's looming water crisis

Water

Climate and socioeconomic change is expected to contribute to water stress in Asia, which means that between 1.6 and 2 billion people could potentially experience severe water stress conditions by 2050. By applying water use scenarios developed by the Water Futures and Solutions Initiative, IIASA researchers for the first time highlighted that socioeconomic change could be the main driver of worsening water security in the region.

Home to almost 4.5 billion people, Asia has experienced unprecedented economic and population growth in recent decades. This has in turn resulted in a substantial increase in water use. Imminent changes due to climate change and socioeconomic development in the region are expected to put even more pressure on water resources in the coming decades. This makes it imperative to evaluate future water scarcity and identify regions at risk in order to inform management strategies, adaptation policies, and planning for sustainable development.

By focusing on Asia as part of a global analysis [1], this study assessed three possible Asian water futures based on a set of consistent and comprehensive climate and socioeconomic projections using three global hydrological models [2]. As part of the modeling process, the researchers extended the latest socioeconomic projections in terms of water, as the original data did not provide enough information for their water use projections. They then combined these extended projections with the latest climate change scenarios using the methodological framework of the IIASA Water Futures and Solutions (WFaS) initiative.

The results highlight that socioeconomic changes have the most significant impacts on water demand growth and overall water stress in hotspots in Asia. While population will peak in some countries before 2050, population and gross domestic product (GDP) are expected to increase in almost all countries across Asia. The resultant growth in, and around mega cities especially, is obvious. Depending on which scenario is applied, industrial and municipal water demands are projected to increase from current levels by between 136-167% or 176-245%.

Climate change is projected to put additional pressure on water resources. In a medium emission scenario, one-third less surface water resources will be available by 2050, when compared to low emissions scenarios. This gap is projected to grow towards the end of the century. Climate change will also result in an increased demand for water in agriculture.

The rapid growth in water demand, in combination with the reduction in available water supply, is expected to increase water stress in Asia considerably, with 20% of the land area subject to severe water stress. The researchers emphasize that a particularly extreme intensification of water stress will occur in the current hotspots of water stress, with an estimated 1.6 to 2 billion people living in the region by 2050. This represents an increase of 38-68% from the 2010s.

Results from a seasonal analysis indicate that most of Asia experiences strong seasonality in water supply and demand, which causes severe water stress over the course of a year, and highlight the need for better planning of water management with season-specific solutions, such as changes in irrigation practices and reservoir operation.

The basin scale hydro-economic analysis also shows that South and East Asian basins have the greatest complexity in terms of the interplay between water availability and climate, with lower coping capacity in South Asian basins. Although coping capacity is expected to improve in all basins, eight basins remain classified in the most vulnerable class (high water complexity combined with low economic strength) by 2050, with large populations living under severe water stress. These regions, in particular, will need effective solutions and better water management to overcome critical water challenges. Increases in coping capacity indicate Asia's potential to achieve this if resources are appropriately allocated.

As a strategic planning method to explore possible futures, this scenario-based approach provides useful insights–particularly in terms of the scale of socioeconomic impacts on water stress. It highlights a clear need for further work on managing water demands and identifying water policy interventions. The analysis, as the first water assessment of Asia in conjunction with socioeconomic projections and climate change scenarios, highlights an urgent need to address water challenges, particularly in the identified hotspots and on the socioeconomic demand side, and underlines the importance of targeted solutions.

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GLOBAL, REGIONAL, NATIONAL

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Further information

- Water Futures and Solutions
- Water Futures and Solutions fast-track analysis
- Global Hydro-economic Model

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In search of perfect foresight

The failure to foresee the catastrophic earthquake, tsunami, and nuclear accident of 2011 was seen by many as a fundamental shortcoming of disaster risk science in Japan. In light of this, the use of scientific knowledge came under renewed scrutiny. Debates continue over an appropriate role of 'evidence-based policy' in earthquake and tsunami risk reduction.

IIASA researchers reviewed publicly available documents on expert committee discussions and scientific articles, to identify continuities and changes observed with regard to the use of scientific knowledge in Japan's disaster risk management.

They found that, while diverse professional opinions on the root causes of their failures were expressed, these generally converge into two interpretations.

The first interpretation—which the researchers call 'the failure of science' perspective—primarily perceived the heart of the issue to be the lack of scientific capacity. According to this view, scientific understanding of the underlying hazards was insufficient, and the disaster risk management (DRM) system, which was designed based on limited knowledge, led to catastrophic failures. Accordingly, options feeding into solutions prescribed by this perspective were also technical and scientific in nature.

The second interpretation—which they termed 'the failure of science-policy institutions' perspective—contended that the root causes stemmed more fundamentally from issues of science-policy processes. In other words, how the country's earthquake and tsunami scientific research agendas were formulated to provide solutions to the threats posed by these hazards. According to this perspective, the sense of urgency created by an imminent threat of major earthquakes and tsunamis, together with unfounded faith in the ability of science to deliver solutions, led to the silencing of open debate and constructive skepticism. The outcome was an eventual misapplication of science in the formulation of DRM policy. The solution prescribed included a major rethink and further engagement of the scientific community in DRM policymaking in the country.

According to the researchers, in general, the prior influence of cognitive biases, such as an over-reliance on documented risks, has been largely recognized, and increased attention is now being paid to the incorporation of less documented, but known risks. This has led to upward adjustments in estimated damages from future risks, and recognition of the need for further strengthening DRM policy. Simultaneously, there remains significant continuity in the way scientific knowledge is perceived to provide sufficient and justifiable grounds for the development and implementation of disaster risk management policy.

The study concludes that the emphasis on 'evidence-based policy' in earthquake and tsunami risk reduction measures continues, despite the critical reflections of a group of scientists who advocate for a major rethink of the country's science-policy set-up, going beyond the limitations of the current state-of-science.

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Further information

- Risk management and adaptation

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Modeling sustainable transport options

Transitions to New Technologies

Novel methodological concepts to simulate pervasive policy-driven transformations were for the first time tested in a real-world case study application to analyze policy targets associated with the city of Shanghai's goal of having more electric vehicles on its roads by 2025.

The IIASA Transitions to New Technologies (TNT) Program's pioneering agent-based modeling approaches, which extend the model representation of dynamic technology landscapes by a corresponding representation of networks of interacting producers and users of technologies, reached a new milestone in 2017. Following extensive model development and illustrative test simulations where the new type of model served primarily as a research tool, it was possible for the first time to calibrate the model with empirical data for a case study in the city of Shanghai.

By combining detailed statistics on vehicle registrations and an innovative application-based consumer survey (albeit with a limited sample size), researchers were able to test the agent-based modeling method in terms of how well it could reproduce the historical rapid growth in the vehicle market of the city. In addition to this, the researchers were able to explore policy options for a policy target scenario of one million electric vehicles in the city by 2025. This work is based on a long-standing successful collaboration with researchers from the East China University of Science and Technology (ECUST) in Shanghai.

First results from the study suggest that this highly ambitious target could be feasible if technology innovation push and social/behavioral pull strategies are combined to change consumer preferences, while maintaining the already highly substantial economic incentives for electric road vehicle purchases.
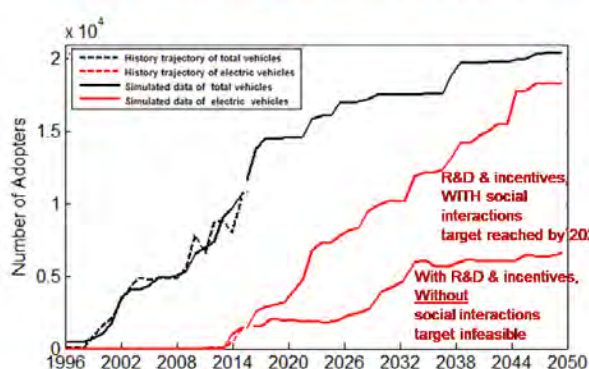
Given this encouraging initial result, a large scale, fully-fledged policy study was initiated. In collaboration with researchers in Israel–who have pioneered novel methods for consumer surveys in new business applications like shared- and electro-mobility–collaborators in China are currently preparing a new, larger scale survey. Research will also continue to extend the agent-based model with an energy systems component that will enable the detailed examination of the resource conservation potential from shared mobility models, as well as the possibility of using a large number of electric vehicle batteries as electricity storage.

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Calibration of historical vehicle market growth in the city of Shanghai with an agent-based model developed by an IIASA-ECUST research team. Also shown are the simulated impacts of technology push policies only, and an integrated approach including demand-pull policies leveraging social network and peer effects. In the latter case, the examined policy target of one million electric cars registered in the city might become feasible by 2028, indicating a case of very rapid transition.

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Further information
- TNT models and databases

Developing an open source energy model

Energy

The IIASA Energy Program (ENE) has developed a new generation of its modeling platform MESSAGEix, which is now available under an open source license. The model is used for research applications, as well as for capacity building in IIASA member countries and teaching at universities.
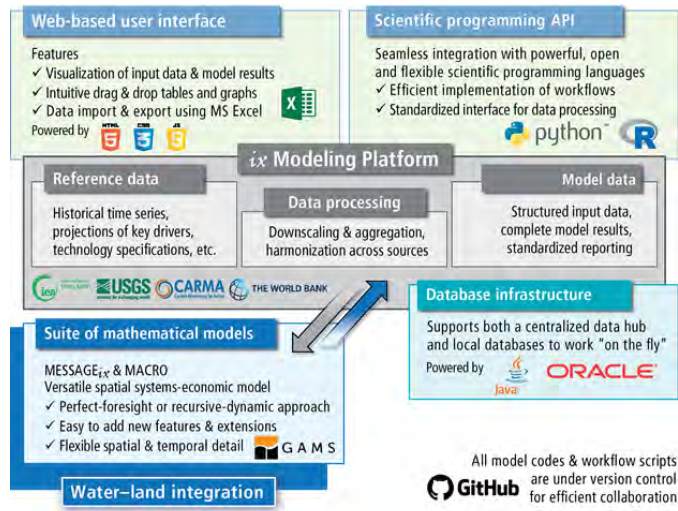
The MESSAGE Integrated Assessment Model developed by ENE has been a central tool in energy-environment-economy systems analysis in the global scientific- and policy arena. It plays a major role in the Intergovernmental Panel on Climate Change (IPCC) assessment reports; it provided marker scenarios of the Representative Concentration Pathways and the Shared Socioeconomic Pathways; and underpinned the analysis of the Global Energy Assessment.

To stay at the frontier of model development, numerical models of human and earth systems need to support higher spatial and temporal resolution, better integrate diverse data sources and methodologies, and become more open and transparent. To deal with these challenges, ENE developed a new modeling platform, called MESSAGEix, which is available under an open source license that facilitates external collaboration and joint model development. This new integrated assessment-modeling platform consists of four building blocks, including an open-source General Algebraic Modeling System (GAMS) implementation of the MESSAGE energy system model integrated with the MACRO economic model; a Java/database version-controlled data management repository; user interfaces for both the

scientific programming languages Python and R for efficient input data and results processing workflows; and a web-based user interface for model/scenario management and intuitive drag-and-drop visualization of results.

The framework aims for the highest level of openness of scientific analysis, bridging the need for transparency with efficient data processing and powerful numerical solvers. The platform is geared toward easy integration of data sources and models across disciplines, spatial scales, and temporal disaggregation levels. All tools apply best practice in collaborative software development and comprehensive documentation of all building blocks, while scripts are generated directly from the GAMS equations and the Java/Python/R source code.

At present, MESSAGEix is being used for building new integrated basin-level modeling tools to address the challenges of the water-energy-land nexus as part of the cross-cutting Integrated Solutions for Water, Energy, and Land (ISWEL) project. The model is also already actively being used by several research organizations in IIASA member countries, for example, the University of Rio de Janeiro in Brazil and TU Munich in Germany. ENE is also supporting government organizations in member countries to develop energy modeling capacity based on the MESSAGEix model, including the National Institution for Transforming India (NITI Aayog) think tank in India and the Ministry of National Infrastructures, Energy, and Water Resources in Israel. Finally, in collaboration with universities, MESSAGEix is used for teaching energy and integrated assessment modeling, at, among others, TU Wien in Austria and Politechnico di Milano in Italy. For this purpose, ENE researchers have developed training materials, including a number of tutorials that are part of the MESSAGEix release.

Components and their interlinkages in the ix modeling platform [1]: web-based user interface, scientific programming interface, modeling platform, database backend, implementation of the MESSAGEix mathematical model formulation.

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Further information

- Model documentation
- Model code (GitHub)

Europe

Selected highlights

Playing for a sustainable future

Economic development and the food-water-energy-environment nexus in Ukraine

Looking ahead: Future opportunities in the greater Eurasian space

A picture paints a thousand words

Member countries

Austria   Finland   Germany   Netherlands   Norway   Russia   Sweden   UK   Ukraine

Playing for a sustainable future

Ecosystems Services and Management

IIASA teamed up with the Organisation for Economic Co-operation and Development (OECD) and the European Commission to test and play The World's Future game—a social simulation game developed by IIASA researchers on the interconnected nature of the Sustainable Development Goals (SDGs). The game sessions provided valuable insights on SDG implementation, while also offering an excellent opportunity for people from different working units and sectors to interact and exchange ideas.

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With the adoption of the 2030 Agenda for Sustainable Development and the 17 SDGs, the international community created a comprehensive and indivisible set of goals attaching equal importance to environmental, social, and economic concerns. This acknowledges for the first time that transformation to sustainable and resilient societies cannot happen with a "business as usual", siloed, approach, and that a systems approach is a necessary condition for successful transformation. Translating this awareness into policymaking processes, however, remains a challenge. A full understanding of the interconnected reality of the SDGs remains elusive, and practitioners are seeking robust tools and guidance that can increase awareness and understanding that will eventually make integrated and coherent policymaking common practice.

To meet the challenge, a number of tools were developed to support policymakers and other actors in society in designing, implementing, and supporting coherent and integrated policies in pursuit of these goals and targets, and to consider transboundary and intergenerational impacts. One such tool is a social simulation game called The World's Future: A Sustainable Development Goals Game. The game was developed during the Systems Analysis Forum (SAF) exploratory project, "Systems Thinking for Transformation", that was led by the Ecosystem Services and Management Program (ESM), in collaboration with the Risk and Resilience Program and the Centre for System Solutions. This serious role-play game is based on scientific systems research, and functions as an experiential training and learning playground. The game challenges participants' understanding of sustainability dynamics and their ability to innovate and collaborate towards the global goals. Specifically, it aims to help players deepen their understanding of the complexities of the global system. This includes identifying and acknowledging the interdependency of actions in pursuit of the goals across policies, regions, and time; better understanding synergies, trade-offs, and feedbacks, as pursuing some goals and targets might undermine the achievement of others; as well as the ability to reflect on negotiation patterns, effective communication, and collaboration.

The OECD gaming session took place in June 2017 and was organized with the unit for Policy Coherence for Sustainable Development. The game prototype was played with an interested group of OECD sectoral experts and

Focal Points from OECD member states, who also helped test and further improve the game through their feedback. At the European Commission, two game sessions were organized with the Directorate-General for International Cooperation and Development's Policy and Coherence unit (DG DEVCO A1)–one session for the unit itself, and one session for staff from other DGs. Both sessions took place in Brussels in October 2017.

The World's Future game was very well received by both institutions, and participants agreed that it was a realistic representation of real world situations and challenges. Although many real-world complexities are expressed in the game, it is important to note that the game is not based on any specific national situation. This means that participants will not necessarily be able to draw direct policy conclusions from the game. However, as a capacity building exercise, players can gain multiple insights to clarify, inspire, and offer guidance in terms of policy decisions in their real-life contexts.

In addition to the sessions held at the European Commission and the OECD, many other groups across Europe, including some at the European Forum Alpbach, the National Youth Agency Austria, and the ScienceCenter-Network Austria, also played The World's Future game in 2017.

Feedback from participants

"It is a humbling and eye-opening experience for us as policy writers – to be confronted with the complexity of policy making in action and trying to find sustainable solutions, even in such a simplified version of reality."

"The game helped to get a better overview of how connected the world is and I can now better visualise the different sectors as one big picture. I also don't easily judge actors in different positions anymore, as one learns how difficult it actually is to achieve something together."

"One key take-away for me was an urgent need to better understand real incentives for different stakeholders to implement change in their industries. What makes them change? We don't really seem to know…"

"I got much clearer insight that policy making is actually messy, based on imperfect understanding of the system and incentives, as well as on imperfect information of what others are doing."

Collaborators

- Organisation for Economic Co-operation and Development (OECD): Ebba Dohlman, Senior Advisor, Policy Coherence for Sustainable Development, Office of the Secretary-General

- European Commission: Amalia Garcia-Tharn, DG DEVCO A1 – International Cooperation and Development, Policy and Coherence

- Centre for Systems Solutions (CRS)

Further information

- A Sustainable Development Goals game

Economic development and the food-water-energy-environment nexus in Ukraine

Advanced Systems Analysis

A new collaborative research program between IIASA researchers and the National Academy of Sciences of Ukraine (NASU) has been set up to provide input to robust solutions and informed policies to ensure sustainable economic development pathways in Ukraine. A cornerstone of the program is the further development and application of the methodology of stochastic optimization, which is used to generate decisions under uncertainty in the food-water-energy-environment nexus.

In 2017, IIASA renewed its strategic collaboration with NASU on the topic of robust solutions for the food-water-energy-environment nexus, by committing to a five-year joint research program. IIASA scientists from the Advanced Systems Analysis (ASA), and Ecosystem Services and Management (ESM) Programs, will collaborate with colleagues from various other IIASA programs, and six NASU institutes (see list of collaborators). They will advance the methodology of stochastic optimization and its application to the integrated analysis of sustainable development of Ukraine. The program also involves policymakers and advisors to raise awareness of the critical dependencies within the food-water-energy-environment complex that has to be considered when planning sectorial development in the country.

To start the new collaboration cycle, the kick-off workshop and a series of follow-up meetings were organized in Kiev in September 2017. IIASA was represented by Yuri Yermoliev from ASA, and Tatiana Ermolieva from ESM. Future work on the program will build on the outputs of the 2012-2016 IIASA-NASU project, among which are recommendations for the 2015 Paris Agreement on Ukrainian energy sector reform, as well as contributions to a Ukrainian Common Cross-cutting Strategy of Agriculture Development.

The project addresses the challenge of building a methodological framework for decentralized optimization, to link agriculture, energy, and water sectorial models. The new framework will allow researchers to devise scenarios and produce recommendations in support of integrated policies in Ukraine that will reveal tradeoffs and synergies, notably under uncertainty, and at different spatial and temporal scales. This is to be based on earlier research [1].

In addition to research and science-to-policy applications, this collaborative project also undertakes capacity development activities. In 2017, a summer school was co-organized by NASU, Taras Shevchenko National University of Ukraine, Glushkov Institute of Cybernetics, and the Norwegian University of Science and Technology. About 50 students from six countries attended the course and benefitted from lectures presented by leading international scientists from various fields, including advanced systems analysis, operations research, and stochastic optimization.

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Collaborators

- Air Quality and Greenhouse Gases Program
- Energy Program
- Transitions to New Technologies Program
- Water Program
- Glushkov Institute of Cybernetics, Ukraine
- Scientific Centre of Aerospace Research of the Earth, Ukraine

- Institute of General Energy, Ukraine
- Institute of Economics and Forecasting, Ukraine
- Institute of Demography and Social Studies, Ukraine
- Institute of Theoretical Physics, Ukraine

Further information

- Workshop of the joint NASU-IIASA project
- Norwegian-Ukrainian Summer School
- Robust food, energy, water, and land management
- Integrated Modeling of Robust Solutions for food, energy, and water security management

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Looking ahead: Future opportunities in the greater Eurasian space

Towards the end of 2017, young researchers, senior experts, and high-level policymakers had the opportunity to engage in vibrant discussions on possible futures for the greater Eurasian space in 2040, and the potential of youth to contribute to economic cooperation and sustainable economic development in the region.

As part of the IIASA Futures Initiative "Challenges and Opportunities of Economic Integration within a wider European and Eurasian Space", IIASA hosted the International Youth Forum: Future of Eurasian and European Integration: Foresight 2040, from 4 to 8 December 2017.

The event was co-organized by IIASA and the Institute for Economic Strategies of the Russian Academy of Sciences, with financial support from the Russian Gorchakov Public Diplomacy Fund.

A total of 40 talented young minds, together with senior experts and high-level policymakers from the European Union, the Eurasian Economic Union, the Commonwealth of Independent States, and East-, and South-East Asia, engaged in a vibrant brainstorming session on possible futures for the greater Eurasian space in 2040. Discussions included issues pertaining to economic-, humanitarian-, and security dimensions. The young participants evaluated the impact that currently emerging trends such as demographic changes, digitalization of the economy, block chains, and 3D-printing are going to have on regional economic integration. A foresight report based on these deliberations will be published in 2018. As a highlight of the forum, the young participants buried a time capsule containing an appeal to the youth of 2040 to be opened in that year.

During the final day of the forum the young researchers took part in the high-level event, "Connectivity, trade, and economic cooperation in the European and Eurasian space", organized by IIASA on the margins of the 24th Organization for Security and Co-operation in Europe (OSCE) Ministerial Council at the Hofburg Palace in Vienna.

Recognizing the potential of youth to contribute to economic cooperation and sustainable economic development, OSCE invited a representative of the Forum to speak to the Council's guests. Marina Steiniger, a junior economist at the Ifo Institute for Economic Research Center for International Economics, was selected to report on how young people perceive future opportunities for closer economic cooperation in the wider European and Eurasian space.

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Funders

- Eurasian Economic Commission
- Eurasian Development Bank

Further information

- Eurasian Economic Integration
- Future of Eurasian and European Integration: Foresight–2040
- High-level session at OSCE Ministerial Council
- Joint workshop on economic integration between Europe and Eurasia
- High-level consultation on Eurasian economic integration

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A picture paints a thousand words

A project run by the IIASA Ecosystem Services and Management Program (ESM) demonstrates how satellite imagery linked with a micro-tasking application such as Picture Pile can support humanitarian efforts. By asking users to answer simple yes-or-no questions, the application employs the help of citizens to detect damaged buildings and other structures over a large area affected by disaster. The idea is to help provide a quick initial damage assessment, so that help can quickly reach those who need it. The workflow established during this project sets the foundation and protocol for future post-disaster damage assessment projects.

According to the World Bank's global risk analysis, around 34% of the world's population live in areas of high mortality risk from two or more natural hazards. This means that timely and innovative methods to rapidly assess damage and subsequently aid relief and recovery efforts are critical. In recent years, several crowdsourcing-based technological tools that engage citizens in carrying out various tasks including data collection, satellite image analysis, and online interactive mapping, were developed to aid efforts in the field of post-disaster damage assessment. One such tool is Picture Pile, a cross-platform application that is designed as a generic and flexible tool for ingesting satellite imagery for rapid classification.

As part of the European Space Agency's Crowd4Sat initiative led by Imperative Space, the team developed a workflow employing Picture Pile for rapid post-disaster damage assessment. In a paper prepared for the European Geophysical Union General Assembly [1], the researchers outline how satellite image interpretation tasks within Picture Pile can be crowdsourced using the example of Hurricane Matthew, which affected large regions of Haiti in September 2016. The application provides simple micro-tasks, where the user is presented with satellite images and asked simple yes-or-no questions. A "before" disaster satellite image is displayed next to an "after" disaster image, and the user is asked to assess whether there is any detectable damage. The question is formulated precisely to focus

the user's attention on a particular aspect of the damage. The user-interface of Picture Pile is built for users to rapidly classify the images by swiping to indicate their answer, thereby efficiently completing the micro-task.

Results of post-disaster damage assessment: satellite image from DigitalGlobe imagery (WorldView 3) of the affected area is available for 10 October 2016 on the left and the result of post-disaster damage assessment using Picture Pile on the right.

This approach will not only help to increase citizen awareness of natural disasters, but will also provide them with a unique opportunity to contribute directly to relief efforts. To ensure confidence in the crowdsourced results, quality assurance methods were integrated during the testing phase of the application using image classifications from experts. The application has a built-in real-time quality assurance system to provide volunteers with feedback when their answer does not correspond with that of an expert.

Picture Pile is intended to supplement existing approaches to post-disaster damage assessment and can be used by different networks of volunteers, for example, the Humanitarian OpenStreetMap Team, to assess damage and create up-to-date maps of response to disaster events. The application has the potential to be integrated into and enhancing existing services that provide rapid post-disaster damage assessments such as the EU's Copernicus Emergency Management Service (Copernicus EMS).

Pre-disaster and post-disaster image pairs presented to the user.

Training images with arrows as damage assessment examples to guide volunteers.

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Collaborators

- Imperative Space, UK
- Humanitarian OpenStreetMap Team (HOT), USA
- European Space Agency (ESA)

Further information

- Monitoring deforestation with Picture Pile
- Citizen science campaign to aid disaster response
- Crowdsourcing for post-disaster damage mapping

Oceania

Selected highlights

Safeguarding the future of the tropics

Global breadbaskets: Possibilities for risk pooling

Member countries

Australia

Safeguarding the future of the tropics

Futures initiatives

The tropics are home to the greatest biodiversity on the planet and provide vital climate regulation. The Tropical Futures Initiative (TFI) brings together scientists from various disciplines and institutions to help governments and key decision makers implement sustainable pathways for these important regions. In 2017, TFI succeeded in becoming the first IIASA Futures Initiative to secure significant external funding under the RESTORE+ project.

The overarching objective of the Restoration for Land Use Sustainability in the Tropics (RESTORE+) project is to provide decision makers in the tropical region with lasting capacity, technical recommendations, and enhanced datasets to inform the restoration of degraded and marginal areas at the Food-Land-Energy nexus. This calls for an approach that links qualitative information with socioeconomic and environmental parameters to obtain a comprehensive assessment of degradation and restoration. Beyond bridging science to policy, RESTORE+ also aims to develop a generic methodology that can be applied to other regions. To this end, while focusing on detailed assessment activities in Indonesia and Brazil, the project also covers the Congo Basin, to conduct dissemination and research outreach activities.

In Indonesia, the project specifically aims to inform key national and sub-national policies such as the country's medium-term economic development plan (or RPJMN as it is commonly referred to in Indonesia), nationally determined contribution (NDC), climate resilience strategy, and national biodiversity strategies and action plan (NBSAP).

Other than quantifyable results, this requires the project to also deliver modeling tools that can be used for further analyses or related inquiries in the broader land use context. RESTORE+ aims to deliver an Indonesia specific modeling toolbox comprising detailed modeling results of the Environmental Policy Integrated Model (EPIC), the Global Forest Model (G4M), the Techno-economic Spatial Optimization Model (BeWhere), enhanced remote sensing products utilizing the citizen-sourced Geo-Wiki approach, and the Global Biosphere Management Model (GLOBIOM). The project will also allow groundtruthing for the usefulness and policy impact of IIASA's exploratory work.

In 2017 for example, the IIASA Wildfire Climate Impacts and Adaptation Model (FLAM), was applied to the Tropics for the first time, with a study devoted to the application of this model to Indonesia. FLAM captures the complex impact of climate, population, and fuel availability on burned areas, using a process-based fire parameterization algorithm that was originally developed to link a fire model with dynamic global vegetation models. The

version of the model applied in Indonesia however, features new modeling approaches compared to the original model applied to Europe. As model development and assessment requires joint capacity building and close collaboration with local stakeholders, enhanced capacity in modeling and the analyses of results are also crucial outcomes of the RESTORE+ project.

In Brazil, RESTORE+ benefits from the successful results of the preceding International Climate Initiative (IKI)-funded REDD Policy Assessment Centre (REDD-PAC) project. Other than generating important technical assessments that forms the basis of Brazil's NDC, REDD-PAC also resulted in the Global Biosphere Management Model (GLOBIOM) for Brazil [1], and other local modeling capacities that will further contribute to the RESTORE+ project. At this stage, the goal of the project is to inform, among others, ministry regulations, and technical- and policy guidelines that contribute to the implementation or enhancement of Brazil's Forest Code to help achieve objectives such as those in its NDC and NBSAP.

In the Congo Basin, project activities focuses on ensuring that stakeholders in the region (e.g., Ministries of Forests and Environment, the Commission of Central African Forests (COMIFAC), CN-REDD offices, and Ministries of Agriculture) endorse the project in terms of its potential contribution to policy formulation and relevant stakeholder activities. Selected training activities will also be undertaken throughout the project to enhance capacity in the region.

A consortium of 10 institutions led by IIASA collaborate on the RESTORE+ project. The project forms part of the IKI and is supported by the German Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety (BMUB).

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IIASA Collaborators

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- World Wildlife Fund (WWF), Indonesia
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- Instituto de Pesquisa Econômica Aplicada (IPEA), Brazil
- UN Environment World Conservation Monitoring Centre (UNEP-WCMC)
- Mercator Institute on Global Commons and Climate Change (MCC), Germany
- Environmental Defence Fund (EDF), USA

- Grantham Research Institute on Climate Change and the Environment (LSE), UK
- Landmapp, Ghana

Further information

- RESTORE+
- FLAM

Global breadbaskets: Possibilities for risk pooling

Simultaneous crop losses in different parts of the world can pose a serious risk to global food security. However, little is currently known about the spatial dependency of crop yield losses between global breadbaskets. In a recent study, IIASA researchers focused on wheat yields to identify systemic risk within specific regions.

The term breadbasket is commonly used to describe an area with highly arable land that produces food–particularly grains–to feed the people of its own country, as well as for export to other places. The increasing global interconnectivity and mutual interdependence of economic- and ecological systems can amplify the vulnerability and risk of disasters. The global food system is a good example of the effects of this increased interdependence and the possibility of systemic risk.

Owing to the globalization of the grain market, a food shock due to drought, or other natural disasters in one or more major food producing areas, can lead to a significant increase in world food prices, and might threaten food security, particularly in poorer countries. This especially applies in the case of extreme events, where one or more breadbaskets are experiencing far below average yields.

Without the necessary information, risk management approaches cannot be applied and vulnerability to extremes may remain high, or even increase around the world in the future. The Risk and Resilience Program tackled both these issues from an empirical perspective, focusing on wheat yield.
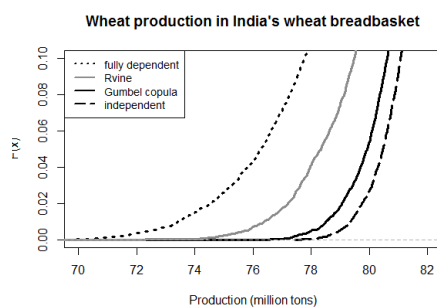

The global wheat breadbaskets.

The researchers estimated the interdependencies between historically observed wheat yield deviations in five breadbaskets: Argentina, Australia, China, India, and the United States. They made use of copula approaches to describe the dependence between variables. In doing so, they were able to attach probabilities to interregional, as well as global yield losses. To increase the robustness of their results, they applied three different methods for constructing multivariate copulas, namely R-vine copulas, ordered coupling using a minimax approach and Gaussian copulas, and

hierarchical structuring.

In the case of the Indian breadbasket with today's average wheat, the use of multiple structuring methods revealed differing results. With a probability of 5% or a 20-year return period, for example, the production in the Indian breadbaskets will be 76.1 million tons if the breadbaskets were fully dependent, 78.5 million tons using the R-vine approach, 79.1 million tons applying a structured copula, and 80.5 million tons if correlations between the states are not considered.

These results show that if correlations between wheat yields within the breadbaskets are not considered in risk analysis, the risk of production losses are underestimated. Using the example above, that would imply that the risk of a production of 80.5 million tons is more than three times higher, assuming that all states are independent compared to the R-vine curve. This is important for crop insurance schemes and agricultural policy decisions.

Wheat production in India's wheat breadbasket

Production curves up to the lower 10th percentile of the production distribution for the Indian breadbasket comparing with minimax structured copula using Gaussian copulas and an R-vine with the independent and fully dependent case with today's average production levels.

On a global scale, however, notwithstanding evidence of global climatic teleconnections that may influence crop production, the researchers demonstrated that wheat production losses are independent between global breadbaskets. This strengthens the case for interregional risk pooling strategies, which could in turn decrease the post-disaster liabilities of governments and international donors.

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Further information

• Risk analysis and modeling

Advanced Systems Analysis

The increasing manifestation and recognition of the systems nature of global challenges, along with the unprecedented availability of data from scientific, governmental, and commercial sources, require more effective and efficient tools for systems analysis and decision support.

The Advanced Systems Analysis Program works in close cooperation with both specialists and decision makers to expedite the recognition and fulfillment of requirements for new systems methods and techniques to meet their needs. In this way, the program develops more efficient solutions to problems or solves those that cannot be addressed by existing tools.

Program website · Scientific recognition · Publications · Staff · Events

Selected highlights

Employing entropy to study growth and resilience in systems

Ecological network analysis reveals systemic impact of threats to ecosystems

Restructuring financial networks to reduce systemic risk

Economic development and the food-water-energy-environment nexus in Ukraine

Objectives

- Enhance the interface between systems analysis methodologies and applications by tailoring methods to present and future needs. In particular, improve the methods and techniques used in decision-support models to deal with nonlinear dynamics, uncertainty, bounded rationality, multiple agents, and multiple objectives.

- Improve the transfer of methods at IIASA through the exploratory co-designing of research questions and methods with end-users. In particular, develop and implement new approaches to analyze the resilience of economic, financial, and ecological networked systems.

- Advance the approaches, practices, and rigor of qualitative research that involves stakeholders and decision makers, and enable the inclusion of results to effectively support decision-making.

- Highlight the utility of advanced systems analysis approaches and techniques in policy-relevant contexts.

Employing entropy to study growth and resilience in systems

Advanced Systems Analysis

A study by researchers from the IIASA Advanced Systems Analysis Program, explored the relation between entropy-based indicators describing system efficiency and redundancy, and system growth and resilience to shocks. In another study they suggested ways to incorporate the properties of non-equilibrium and path-dependency into the traditional notion of entropy to better describe real-life human-earth systems.

Entropy is a concept that links the microscopic world with macroscopic (systemic) phenomena and defines the degree of disorder in a system. It was first introduced in physics to relate the velocities of particles (microscopic world) with temperature (macroscopic property). It is useful for describing and analyzing various complex systems consisting of a large number of interacting elements, where the concern of decision makers is on macroscopic parameters, while dynamics unfold at the micro-level of individual elements. In a closed system, entropy will always increase, while open systems, including all environmental and social systems, are able to manage the rate of entropy generation to some degree by maintaining a network structure.

Many real-life complex systems are networked systems. Food webs, for example, are networks of species feeding on one another, supply chains are networks of firms supplying intermediate goods to each other, and social systems are networks of people exchanging information and opinions–to name just a few. In systems, where the number of network elements is large and the connections are subject to so many factors that they can be seen as random to some degree, the concept of (information) entropy becomes applicable.

The study analyzed global commodity trade using the information entropy concept [1]. Its complex network structure arises from bilateral and multilateral trade agreements. The researchers found that trade agreements can make commodity trade networks more efficient and lead to more rapid growth in the volume of trade. However, these gains come at the expense of resilience to economic shocks, such as the 2009 global financial crisis, which decimated economies around the world. Perhaps counter intuitively, the results also showed that networks that had greater redundancies did not have to sacrifice growth.

Since complex systems are highly interconnected, traditional Gaussian statistics is not applicable to them. The statistics of complex systems is the statistics of power laws, where large and extreme events appear much more often than Gaussian statistics predicts. In earlier research [2], IIASA researchers suggested a way to extend the notion of entropy to systems that are networked and history dependent, to make it more applicable to complex human-earth systems. In this study, they showed that simple path-dependent systems, such as situations with a winner-takes-all dynamic, can indeed be studied by means of developed generalized entropy. Winner-takes-all dynamics appear in many socioeconomic and environmental contexts, which show strong reinforcement and hence "fat tailed" distributions. This in turn implies that catastrophic events with high impacts happen more often than common sense suggests.

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IIASA BY PROGRAM

Further information

- Interactions within systems
- Preferential trade agreements enhance global trade at the expense of its resilience

Ecological network analysis reveals systemic impact of threats to ecosystems

Advanced Systems Analysis

Ecological network analysis provides a systematic approach to assess the direct and indirect influences that one network node has on another. Researchers from the IIASA Advanced Systems Analysis Program engage in projects to develop these methodologies further and to explore new applications.

As part of the Southern African Young Scientists Summer Program (SA-YSSP), IIASA researchers conducted systems analysis on a food web ecosystem in an estuary near Durban, South Africa [1]. The food web was analyzed using a novel methodology to identify keystone species (i.e., organisms that play a unique and crucial role in the way an ecosystem functions). The importance of a species was measured by the degree to which it influences other species or functional groups. While other keystone measures focus on the overall influence, this method differs because of a biomass-normalization that removes the bias of larger biomass compartments (i.e., the total quantity or weight of organisms in a given area) such as phytoplankton and detritus. This approach highlights the ecosystem interactions of smaller, typically top predator species. The results revealed that several predatory fish groups exhibited strong top-down control on the ecosystem. The research also utilized a unique time series dataset that allowed for investigation of changes in the food web during different seasons and different hydrological conditions. The study concluded that the ecosystem, in terms of the keystone species, remained resistant to these changes and other imposed disturbances.

Another network project undertaken during the Young Scientists Summer Program, and subsequently awarded the Peccei Award, employed a novel "networks of networks" approach that utilized both social and ecological network data [2]. A series of 19 reservoirs in Nebraska, USA, were studied to determine the spread of an invasive snail species. Food webs for each of the reservoirs were constructed based on collected field data. The invasive species were identified in five reservoirs. These reservoirs were considered contagious, as it was known that the snails could be spread to other reservoirs by anglers. Social network data showed how anglers moved from one reservoir to another based on their fishing preferences–where they had last fished and where they intended to fish next. The snails attach themselves to boats and in this way have a chance of being transported to other reservoirs. Hence, researchers considered the uninfected reservoirs susceptible to invasion. Once the species were introduced to a new reservoir by anglers moving between the different bodies of water, the reservoir was "infected" and the food web model in that reservoir would change as a result of the invaders' feeding patterns. At some point, the snail population in the newly infected reservoir would

grow large enough to be contagious and the contamination process would be repeated. This network of networks approach identified which reservoirs are critical to avoid outward spread and inward infection, in order to slow the presence of the invasive species.

In a third study, an ecological network approach was used as the foundation for understanding system sustainability [3]. All systems are open thermodynamic systems, in other words, they freely exchange energy and matter with their surroundings. This means that how they organize to use this energy is key to their sustainability. The IIASA researchers found that networks that maximize the total flow of energy or matter through the system and the time that energy/material stays in a particular compartment of the system via cycling, are also the ones that can best slow down energy dissipation and thus achieve greater levels of energy extracted from available resources. According to this study, structural-, and functional organization that follows this pattern is observed in ecosystems and may prove to be a useful template for designing human, socioeconomic systems.

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IIASA BY PROGRAM

Further information

- Young Scientists Summer Program (YSSP)

- Southern African Young Scientists Summer Program (SA-YSSP)

Restructuring financial networks to reduce systemic risk

Research by the IIASA Advanced Systems Analysis Program shows that the Basel III international regulatory framework for banks will not reduce systemic risk in the financial sector as planned. The results suggest that regulations should instead aim to increase the resilience of financial networks by restructuring them.

A resilient banking sector is a necessary condition for achieving sustained economic growth. The Basel III regulatory framework for banks is a new set of international banking regulations that were proposed after the financial crisis of 2007-2008, which aims to reduce the risk of a similar crisis in the future. The regulations, which are currently under intense discussion, would set higher requirements for bank capital and liquidity reserves and introduce capital surcharges for systemically important banks, that is, those that are "too big to fail."

One important aim of the Basel III framework is to reduce the risk of system-wide shocks in the financial sector. It is therefore essential that Basel III address the problem of systemic risk in the financial system in an appropriate way.

However, a recent study by IIASA researchers [1] showed that the capital surcharges would have to be much higher than those currently set to be effective, which would in turn lead to a severe loss of efficiency in the financial system.

The research is based on a state-of-the-art agent-based model of a financial system and the real economy developed earlier [2] [3]. Using the model, a series of numerical experiments, simulating different types of regulations and their impacts on risk and resilience in the financial system, were performed. The researchers found that replacing the currently proposed Basel III regulations with different regulation schemes that aim to re-structure financial networks, would be much more effective in increasing resilience while avoiding the loss of efficiency in markets. Such regulations could include smart transaction taxes based on the level of systemic risk, which IIASA researchers proposed in an earlier study [2] to reshape the topology of financial networks.

The study further highlights how important data-driven agent-based modeling has become as a tool to help identify the unintended consequences of regulations, and propose more effective solutions. As the international banking system is complex and intricately connected, it is important to analyze how regulations will affect financial networks from a systemic perspective in order to draft intelligent regulations.

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Further information

- Optimal behavior of systems
- New international banking rules would not prevent another financial crisis

Economic development and the food-water-energy-environment nexus in Ukraine

Advanced Systems Analysis

A new collaborative research program between IIASA researchers and the National Academy of Sciences of Ukraine (NASU) has been set up to provide input to robust solutions and informed policies to ensure sustainable economic development pathways in Ukraine. A cornerstone of the program is the further development and application of the methodology of stochastic optimization, which is used to generate decisions under uncertainty in the food-water-energy-environment nexus.

In 2017, IIASA renewed its strategic collaboration with NASU on the topic of robust solutions for the food-water-energy-environment nexus, by committing to a five-year joint research program. IIASA scientists from the Advanced Systems Analysis (ASA), and Ecosystem Services and Management (ESM) Programs, will collaborate with colleagues from various other IIASA programs, and six NASU institutes (see list of collaborators). They will advance the methodology of stochastic optimization and its application to the integrated analysis of sustainable development of Ukraine. The program also involves policymakers and advisors to raise awareness of the critical dependencies within the food-water-energy-environment complex that has to be considered when planning sectorial development in the country.

To start the new collaboration cycle, the kick-off workshop and a series of follow-up meetings were organized in Kiev in September 2017. IIASA was represented by Yuri Yermoliev from ASA, and Tatiana Ermolieva from ESM. Future work on the program will build on the outputs of the 2012-2016 IIASA-NASU project, among which are recommendations for the 2015 Paris Agreement on Ukrainian energy sector reform, as well as contributions to a Ukrainian Common Cross-cutting Strategy of Agriculture Development.

The project addresses the challenge of building a methodological framework for decentralized optimization, to link agriculture, energy, and water sectorial models. The new framework will allow researchers to devise scenarios and produce recommendations in support of integrated policies in Ukraine that will reveal tradeoffs and synergies, notably under uncertainty, and at different spatial and temporal scales. This is to be based on earlier research [1].

In addition to research and science-to-policy applications, this collaborative project also undertakes capacity development activities. In 2017, a summer school was co-organized by NASU, Taras Shevchenko National University of Ukraine, Glushkov Institute of Cybernetics, and the Norwegian University of Science and Technology. About 50 students from six countries attended the course and benefitted from lectures presented by leading international scientists from various fields, including advanced systems analysis, operations research, and stochastic optimization.

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Collaborators

- Air Quality and Greenhouse Gases Program
- Energy Program
- Transitions to New Technologies Program
- Water Program
- Glushkov Institute of Cybernetics, Ukraine
- Scientific Centre of Aerospace Research of the Earth, Ukraine
- Institute of General Energy, Ukraine
- Institute of Economics and Forecasting, Ukraine
- Institute of Demography and Social Studies, Ukraine
- Institute of Theoretical Physics, Ukraine

Further information

- Workshop of the joint NASU-IIASA project
- Norwegian-Ukrainian Summer School
- Robust food, energy, water, and land management
- Integrated Modeling of Robust Solutions for food, energy, and water security management

Air Quality and Greenhouse Gases

The IIASA systems approach to air quality and greenhouse gas management is a unique example of a successful science-policy interface shaping global, regional, and national policies. Pioneering, interdisciplinary research into the interplay between rural and urban air pollution will provide the badly needed evidence to support measures that deliver local and near-term benefits while also contributing to global and long-term policy targets.

Program website   Scientific recognition   Publications   Staff   Events

Selected highlights

Weighing up the costs of keeping cool

Meeting ambitious climate mitigation targets

Oil production releases more methane than previously thought

Trade-offs between cutting air pollution and worsening climate damage

Objectives

- Develop an integrated approach relevant for urban policymakers in industrialized and developing countries, with intuitive user-interfaces for decision makers and stakeholders not trained in systemic air quality management.

- Quantify the interplay between urban and rural air pollution, considering the physical exchange of pollution in the atmosphere, diversity in emission sources, health impacts, and social factors.

- Analyze the drivers and sources of air pollution and their impacts on design policy interventions that deliver benefits to different social groups and economic sectors.

- Establish a new urban management tool for practical policy analyses in a variety of cities in industrialized and developing countries.

- Connect the new urban analysis tool with the global Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) tool to explore the regional and global effects of urban decisions.

- Quantify the contributions of specific policy interventions in achieving the UN Sustainable Development Goals.

Weighing up the costs of keeping cool

Air Quality and Greenhouse Gases

In October 2016, a global decrease in the use of certain greenhouse gases commonly used in a number of industries across the globe was agreed under the Kigali Amendment to the Montreal Protocol. A new study by the IIASA Air Quality and Greenhouse Gases program however, found that the cost burden of compliance with this amendment will be unevenly distributed across sectors and world regions, which justifies a redistribution of costs between now and the target date of 2050.

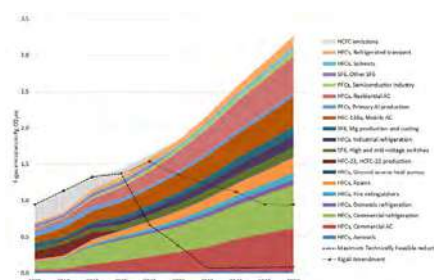Room air conditioners near Kahn market, New Delhi. © Anders Isaakson

Hydrofluorocarbons (HFCs) are synthetically produced chemicals that are widely used as cooling agents in, for example, air conditioning and refrigeration systems, or as components in the production of, among other products, foams and aerosols. Although they have strong global warming properties, these gases do not affect the ozone layer. As a result, manufacturers have been using them to replace the ozone depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) that are regulated under the Montreal Protocol. With increasing demand for the cooling and other services offered by HFCs and other fluorinated gases (F-gases) however, emissions of these powerful greenhouse gases are on the rise.

The GAINS model developed by IIASA researchers explores cost-effective emission control strategies that simultaneously tackle local air quality and greenhouse gases to maximize benefits at all scales. It assesses emissions on a medium-term time horizon, and specifies projections in five-year intervals until the year 2050. Researchers from the Air Quality and Greenhouse Gases program recently extended this model with a capacity to develop global emission scenarios for the F-gases, HFCs, perfluorocarbons (PFCs), and sulphur hexafluoride (SF6) [1].

Since its launch in 2006, GAINS has been implemented for the whole world, distinguishing 172 regions including 48 European countries and 46 provinces/states in China and India. The new resolution at the sector and technology level for each of the 172 regions is intended to provide sufficient detail to develop cost-effective emission reduction strategies for F-gases. When accounting for existing regional and national F-gas regulations, baseline F-gas emissions are expected to increase from about 0.7 to 3.3 Pg CO2eq between 2005 and 2050, of which HFC emissions alone make up about 2.9 Pg CO2eq in 2050. Growth in emissions is particularly pronounced in developing countries owing to an expected strong increase in demand for stationary and mobile air conditioning.

According to the researchers, the provisions of the Kigali Amendment could remove 61% of cumulative HFC emissions over the period 2018 to

Baseline emissions of F-gases (HFCs, PFCs, and SF6) 2005 to 2050 by source sector. HCFC emissions are summed up at the top of the graph.

2050 compared to expected emissions without implementation of the amendment [2]. It would be technically possible to remove as much as 84% if existing technology is employed to a maximum extent. Implementation costs are expected to remain very low in the coming two decades, but to rise sharply in the final decade leading up to 2050, unless future costs decline due to technological development and a full realization of expected energy-savings through careful implementation of alternatives to HFCs.

In a report prepared for the UN Environment Program on the impacts of the Kigali Amendment in Asia [3], the researchers also found that the expected CO2 reductions from electricity-savings linked to properly installed and maintained alternative technologies to HFCs, add about 10 to 12% of savings in greenhouse gas emissions to the total savings from a reduction in HFCs. Both estimates of costs and possible energy savings are potentially useful information for Parties to the Montreal Protocol when they next meet to set up the Multilateral Fund, which will alleviate some of the cost burden on developing countries to comply with the Kigali Amendment.

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IIASA contributors

- Pallav Purohit
- Lena Höglund-Isaksson

Further information

- Global scenarios for F-gas emissions
- The GAINS Model

- GAINS: Comparing GHG Mitigation Efforts between Annex I Countries

Meeting ambitious climate mitigation targets

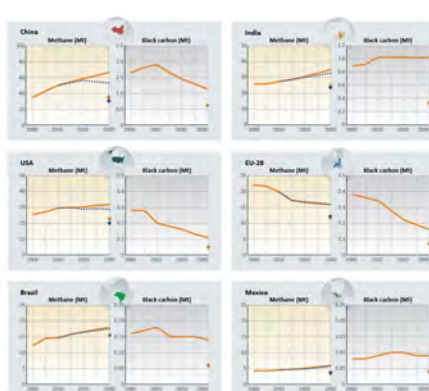Air Quality and Greenhouse Gases

Research shows that reducing the emissions of short-lived climate pollutants (SLCPs) will play an important role in meeting the 2°C target of the Paris Agreement. Although these emissions will be partially reduced as a consequence of carbon dioxide (CO2) mitigation, it will not be enough. According to the IIASA Air Quality and Greenhouse Gases (AIR) Program, additional, dedicated SLCP policies that will also deliver other benefits such as improved health will be needed.

Anthropogenic climate change is largely driven by human-induced changes in the composition of the atmosphere, including long-lived greenhouse gases that have lifetimes of approximately eight years or more, and SLCPs that have lifetimes of approximately 20 years or less. The challenge with SLCPs is that reducing their emissions may lead to undesired warming in the atmosphere. However, many SLCPs are also considered air pollutants that have negative effects on human health, crop productivity, and ecosystems.

The IIASA AIR program has been a forerunner in analyzing the role that SLCPs could play in meeting ambitious climate mitigation targets. In 2017, researchers concluded a number of important research projects in this field. These include an improved estimate of current and past emissions of black carbon (one of the notorious SLCPs) [1]; an analysis of how changing emissions of aerosol precursors have influenced the radiative balance of the planet in past decades [2]; an innovative analysis of the contribution of solid fuel cook stoves to the aerosol load in the atmosphere [3]; and an analysis of the interactions between SLCP mitigation and the sustainable development goals [4].

Led by Zbigniew Klimont and coauthored by Lena Hoglund-Isaaskson, both from IIASA, Chapter 6 of the 2017 UN Environment Program (UNEP) Gap report is dedicated to the role that SLCPs could play in achieving ambitious long-term global temperature targets. The team, which consisted largely of AIR program researchers and their current collaborators, highlighted that reductions in SLCPs are most effective when accompanied by reductions in CO2. Since CO2 and SLCPs often have the same sources, synergies can be reaped in reduction efforts. The researchers however caution that some pollutants are not co-emitted and need to be targeted individually. Moreover, because they have a shorter lifespan and thus influence the atmosphere in characteristically different ways, it is neither useful nor appropriate to translate SLCF mitigation to carbon-equivalent units. The authors recommend that long-lived greenhouse gases and SLCPs should be considered and targeted separately with policies tied to specific, non-convertible measures.

The UNEP report concludes that SLCF potential emission reductions are significant. It states that SLCP reductions will be an integral part of a strategy that aims to keep global temperature increases to less than 2°C, and that early reductions would not only help to slow the rate of climate change in the short term, but also provide substantial health benefits. In the

Regional baseline methane and black carbon [shaded background] emissions and mitigation potential by 2030 [Mt per year].

future, coreductions of SLCF because of CO2 reductions will play a role, but additional specific policies for SLCPs will be needed.

Over the past few years, the AIR program has also significantly extended and improved estimates of mitigation potentials and the costs of reducing SLCPs. This helps to better understand and design cost-effective strategies to reduce future climate change impacts in a complex world of interacting atmospheric processes and economic and environmental constraints.

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Further information

- Global emission fields of air pollutants and GHGs
- Impacts of Short-Lived Air Pollutants
- Benefits from Reducing Short-lived Climate Forcers

IIASA BY PROGRAM

Oil production releases more methane than previously thought

Air Quality and Greenhouse Gases

A new study from the IIASA Air Quality and Greenhouse Gases Program, which for the first time takes into account different production management systems and geological conditions around the world, shows that global methane and ethane emissions from oil production between 1980 and 2012 were far higher than previously thought.

Methane is a potent greenhouse gas, which scientists rank as the second-most important contributor to climate change after CO2. Yet, while methane concentrations in the atmosphere can be easily measured, it is difficult to determine the contribution of different sources, whether human or natural. This information is necessary for reducing emissions.

The layer of gas that is present above the oil in an oil reservoir, has a methane content of 50 to 85%. When the oil is pumped to the surface, this gas also escapes. In oil production facilities in North America, almost all of this gas is recovered and the portion that is not is mostly flared to prevent leakage and potential explosions, while a very small fraction is simply vented. In other parts of the world where recovery rates are lower, much larger quantities of this gas are released into the atmosphere.

Previous global bottom-up emission inventories of methane used rather simplistic approaches for estimating methane from oil production, merely taking the few direct measurements that exist from North American oil fields and scaling them with oil production worldwide. This approach however, leaves considerable room for error, which prompted an IIASA researcher to develop a new method that could better account for the many variations in oil production around the world.

In a paper on this work that was published in the journal Environmental Research Letters [1], global methane emissions from oil and gas systems in over 100 countries were estimated over a 32-year period. A variety of country-specific data was used, ranging from reported volumes of associated gas to satellite imagery that can show flaring, as well as atmospheric measurements of ethane, a gas which is released along with methane and easier to link more directly to oil and gas activities.

The study found that, especially in the 1980s, global methane emissions were as much as double the amount previously estimated. The results also show that the Russian oil industry contributes a large amount to global methane emissions. A decline in the Russian oil industry in the 1990s contributed to a global decline in methane emissions, which continued

until the early 2000's. At the same time, methane recovery systems were becoming more common and helping to reduce emissions. Yet, since 2005, emissions from oil and gas systems have remained fairly constant, which according to the research, is likely linked to increasing shale gas production that largely offsets emission reductions from increased gas recovery.
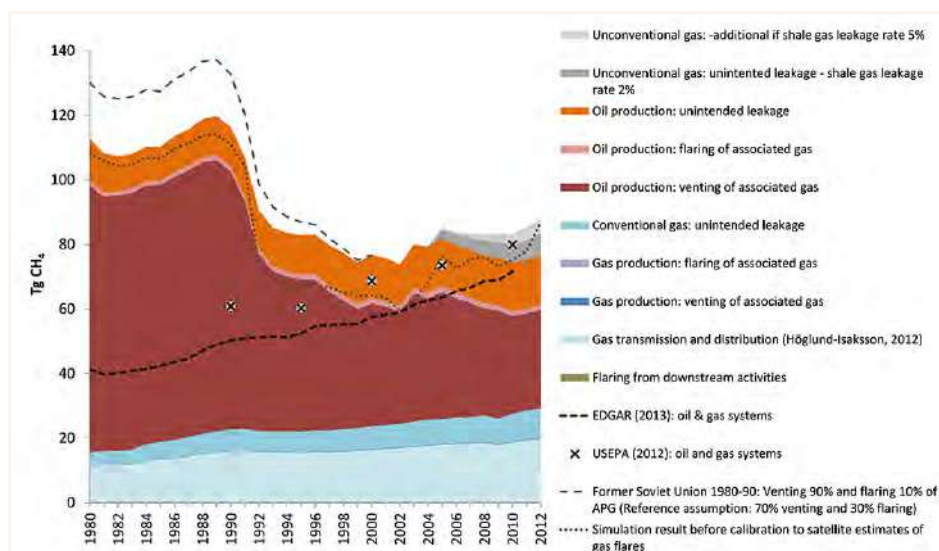
Graph showing the sources of methane from oil production since 1980.

The study points out that these estimates are only as good as the data allow and that there is still uncertainty in the numbers. To improve the data, a close collaboration between the scientific measurement community and the oil and gas industry would be needed to make more direct measurements available from different parts of the world.

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Further information

- Oil production releases more methane than previously thought

Trade-offs between cutting air pollution and worsening climate damage

Air Quality and Greenhouse Gases

According to new research conducted by researchers from the IIASA Air Quality and Greenhouse Gases Program in collaboration with scientists in China and the USA, synthetic natural gas represents a trade-off between reducing air pollution and increasing greenhouse gas emissions in China.

China's industrial regions have been plagued by severe air pollution in recent decades and the situation has received worldwide attention thanks to photos of Beijing and other smog-blanketed Chinese cities. More than just an eyesore, China's smog has created a public health crisis that has led the Chinese government to declare war on air pollution. Air pollution contributes to cardiovascular disease, lung cancer and emphysema, among other illnesses and in China specifically, causes about 1.6 million people to die prematurely each year. This accounts for more than a quarter of annual deaths that can be attributed to air pollution.

Driven by this public health emergency and a desire to rely on its large supplies of coal, China has plans to substantially expand its production of synthetic natural gas (SNG). Around 40 SNG plants have been approved or are currently under construction in the country. In addition, as part of the Paris climate agreements, China has committed to peaking its CO2 emissions by 2030 or sooner.

SNG is a fuel derived from coal that is relatively free of conventional air pollutants. For China, this fuel source represents a trade-off. Using SNG instead of coal could improve air quality and public health by reducing illness and premature mortalities due to air pollution, but it would also markedly increase CO2 emissions, because creating synthetic natural gas from coal produces more CO2 than burning the coal directly.

Given China's plans to produce SNG, the new study [1] examined possible ways for China to maximize improvements in air quality while minimizing the additional CO2 emitted from the production and use of this fuel source. Yue Qin, a former participant of the Young Scientists Summer Program (2016), along with Fabian Wagner and other colleagues at IIASA developed a sophisticated modeling approach to estimate both health outcomes and carbon emissions under various SNG-use scenarios. Their goal was to determine whether the Chinese government might have options for optimizing deployment of SNG to minimize the climate penalty, while maximizing the health benefits of reduced air pollution.

The study examined the impact of switching from coal to SNG in three broad areas: electricity production, industry, and residential use. They found that switching to SNG in industry and electricity production would have little impact on smog-related deaths and cause a major increase in CO2 emissions. However, the results also showed that switching from coal to SNG for residential uses, such as heating and cooking, would substantially reduce deaths due to air pollution and increase emissions of CO2 to a lesser extent than the alternative. The smaller environmental impact of using SNG in the residential sector results because residential coal combustion in small stoves is inherently inefficient and has uncontrolled emissions of air pollutants. Coal combustion in the power and industrial sectors on the other hand, is more efficient and pollution control devices reduce emissions of health damaging air pollutants, thus reducing the benefits of switching to SNG.

SNG plants convert coal to a form of natural gas by a variety of methods that are typically energy intensive. As a result, it is a less efficient fuel than coal because of the energy involved in the gas's creation. The researchers found that using synthetic natural gas to generate electricity, for example, results in 60% more CO2 emissions than using coal-fired generators.

One benefit of SNG is that toxic sulfur and nitrogen compounds are removed from the coal as part of the production process. Compared to coal-fired electric plants, this difference is relatively minor, as modern coal plants remove much of these pollutants. When SNG is however used in the residential sector, it produces far less pollution than the use of coal.

Comparison of CO2 emission changes and avoided premature mortality under various synthetic natural gas (SNG) allocation scenarios relative to the use of coal. Results for standard SNG scenarios all find increases in CO2 emissions while results that include Carbon Capture and Storage (CCS) and the use of conventional natural gas (NG) all result in reductions in CO2 emissions. Solid circles represent SNG without applying CCS, and open circles represent SNG with CCS applied during SNG production. Solid triangles represent the outcome when conventional natural gas is used without CCS. We assume that electricity provided for SNG_CCS is from natural gas combined cycle (NGCC) power plants using CCS.

The study concluded that deploying synthetic natural gas in the residential sector would substantially improve air quality and reduce premature deaths associated with outdoor air pollution with the smallest increase in CO2 emissions compared with the power and industrial sectors. However, the results also indicate that in no case can SNG simultaneously meet the desire to improve air quality while reducing carbon emissions.

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Further information

- Synthetic gas would cut air pollution but worsen climate damage in China

Ecosystems Services and Management

The Ecosystem Services and Management Program (ESM) has built integrated knowledge and data systems to provide a trusted science base for land management policy processes in many global regions. These aim to improve human wellbeing and sustainable management of the Earth's natural resources. Guiding production and consumption choices that are consistent across scales and compatible with the maintenance of equitable access to multiple ecosystem services, is a scientific challenge that ESM is uniquely positioned to address based on its cluster of citizen science and modularly linked land resource assessment tools.

(Program website) (Scientific recognition) (Publications) (Staff) (Events)

Selected highlights

Transforming agriculture in Mexico

A picture paints a thousand words

Playing for a sustainable future

Improving projections of future land use and environmental impacts

Objectives

- Initiate and support global policy processes aimed at achieving the UN Sustainable Development Goals (SDGs) by focusing on integrated multiple natural resource use strategies and monitoring systems.

- Undertake at least three globally consistent national/regional policy impact assessments relevant to the three Rio Conventions with a potential focus on supporting the measurability of global land restoration initiatives.

- Launch an annual global commodity market and resources review (including special feature themes such as societal resource-based risks assessment), starting in 2020 with participation of consortium members recruited from IIASA member countries. Create a global natural/bio-resources market assessment network or consortium.

- Establish an online open access platform for the market assessment consortium by 2020 (including a quantified commodity market outlook). The outlook will start with agriculture and forest sector commodities and will be expanded to eventually also include minerals and metals markets.

- Establish the global Citizen Science Center (CSC) to initiate, host, and coordinate citizen initiatives aimed at crowd sourcing scientific data (inbound) and bringing research outputs to a wide audience (outbound).

- Expected impact:

  1. Newly designed knowledge systems that drive incremental and transformational policies for ecosystem management and improved human and environmental wellbeing.

  2. Resulting portfolios of policy instruments (including observation systems) that are consistent across space, time, and economic/environmental sectors.
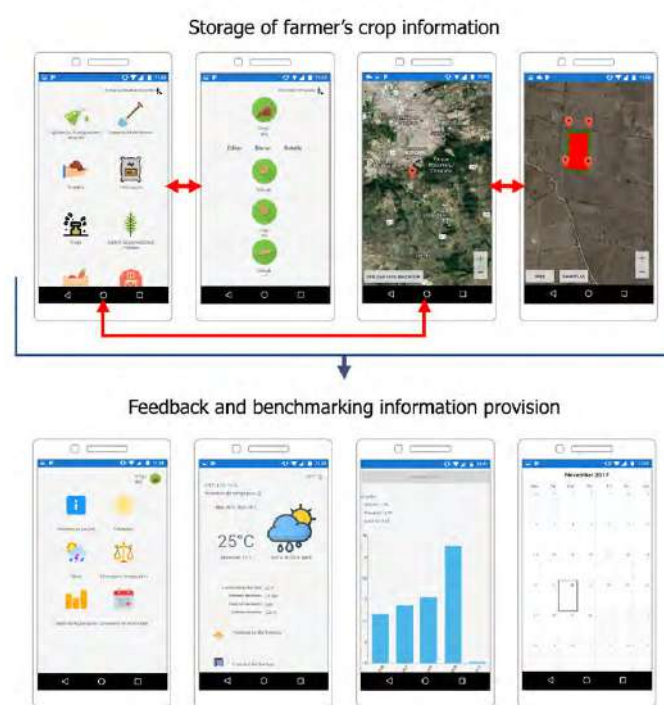
Transforming agriculture in Mexico

A freely available mobile application developed by IIASA researchers in collaboration with the International Maize and Wheat Improvement Center (known by its Spanish acronym CIMMYT), is providing farmers in Mexico with tutorials and expert advice to improve their farming practices and crop yields.

The Agrotutor application is an output of the Ecosystem Services and Management Program's Technological Portfolios and Modeling Techniques for Sustainable Intensification Project. The current version of the application allows farmers to create a user profile and register land parcels and the crops grown on them at different periods throughout the season. The app then provides the farmer with timely agronomical recommendations, potential yield, and financial benchmarking information, as well as historical and forecasted weather data.

The application uses the mobile phone's global positioning system (GPS) to geo-reference the registered land parcel, and gives the farmer access to very high-resolution Google satellite imagery of the land parcel in question. The farmer can delineate the parcels and introduce basic information such as the crop and cultivar planted (including maturity type and ideal climate), and the planting date. It is also possible to record CIMMYT-promoted parcel technologies and all agronomical activities performed, such as fertilization, irrigation, and pest management, as well as additional detail on these activities including costs, products used, and dosages applied.

Once the basic information and geo-location of a land parcel have been registered, the application provides crop and location-specific information representing large data sets and calculations in a simplified way. This includes the outputs of the IIASA Environmental Policy Integrated Climate (EPIC) crop model, which show potential performance (yield) for five different years for irrigated and non-irrigated areas. Based on extensive CIMMYT ground data, anonymous benchmarking information regarding costs, income, utility, and performance (yield), as well as current, forecasted, and historical weather information, are also included. In addition to these outputs, a series of windows of opportunity are shown in calendar format, where the application suggests optimal periods to execute agronomical activities (e.g., fertilization) on the selected parcels by taking into account growing degree days (from planting date onwards), as well as selected maturity and ideal climate for the specified cultivar. Farmers can also access links to tailor made materials previously developed by CIMMYT, such as tutorials for best agronomical practices.

Since the application was built in a modular way, future possibilities for expansion include delivering a larger variety of data such as market and financial information with the ultimate goal being to eventually provide farmers with a full Decision Support System. Such a system would use crowdsourced information obtained through the mobile application, which

could then be combined with data from price and market forecast models. These models (currently running at IIASA) would in turn give the farmer predicted buying/selling information for a given period or season. By coupling such forecasting systems with machine learning, crop modeling could enhance the results even further, thus simultaneously providing farmers with accurate and reliable technical and financial information. These additional features will be explored during the second phase of the project in 2018.

CIMMYT IIASA Agrotutor mobile application.

Further information

- Crowdsourcing Farmers' Data

A picture paints a thousand words
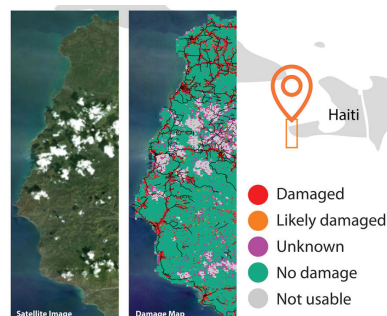
A project run by the IIASA Ecosystem Services and Management Program (ESM) demonstrates how satellite imagery linked with a micro-tasking application such as Picture Pile can support humanitarian efforts. By asking users to answer simple yes-or-no questions, the application employs the help of citizens to detect damaged buildings and other structures over a large area affected by disaster. The idea is to help provide a quick initial damage assessment, so that help can quickly reach those who need it. The workflow established during this project sets the foundation and protocol for future post-disaster damage assessment projects.

According to the World Bank's global risk analysis, around 34% of the world's population live in areas of high mortality risk from two or more natural hazards. This means that timely and innovative methods to rapidly assess damage and subsequently aid relief and recovery efforts are critical. In recent years, several crowdsourcing-based technological tools that engage citizens in carrying out various tasks including data collection, satellite image analysis, and online interactive mapping, were developed to aid efforts in the field of post-disaster damage assessment. One such tool is Picture Pile, a cross-platform application that is designed as a generic and flexible tool for ingesting satellite imagery for rapid classification.

As part of the European Space Agency's Crowd4Sat initiative led by Imperative Space, the team developed a workflow employing Picture Pile for rapid post-disaster damage assessment. In a paper prepared for the European Geophysical Union General Assembly [1], the researchers outline how satellite image interpretation tasks within Picture Pile can be crowdsourced using the example of Hurricane Matthew, which affected large regions of Haiti in September 2016. The application provides simple micro-tasks, where the user is presented with satellite images and asked simple yes-or-no questions. A "before" disaster satellite image is displayed next to an "after" disaster image, and the user is asked to assess whether there is any detectable damage. The question is formulated precisely to focus

the user's attention on a particular aspect of the damage. The user-interface of Picture Pile is built for users to rapidly classify the images by swiping to indicate their answer, thereby efficiently completing the micro-task.

Results of post-disaster damage assessment: satellite image from DigitalGlobe imagery (WorldView 3) of the affected area is available for 10 October 2016 on the left and the result of post-disaster damage assessment using Picture Pile on the right.

This approach will not only help to increase citizen awareness of natural disasters, but will also provide them with a unique opportunity to contribute directly to relief efforts. To ensure confidence in the crowdsourced results, quality assurance methods were integrated during the testing phase of the application using image classifications from experts. The application has a built-in real-time quality assurance system to provide volunteers with feedback when their answer does not correspond with that of an expert.

Picture Pile is intended to supplement existing approaches to post-disaster damage assessment and can be used by different networks of volunteers, for example, the Humanitarian OpenStreetMap Team, to assess damage and create up-to-date maps of response to disaster events. The application has the potential to be integrated into and enhancing existing services that provide rapid post-disaster damage assessments such as the EU's Copernicus Emergency Management Service (Copernicus EMS).

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Pre-disaster and post-disaster image pairs presented to the user.

Training images with arrows as damage assessment examples to guide volunteers.
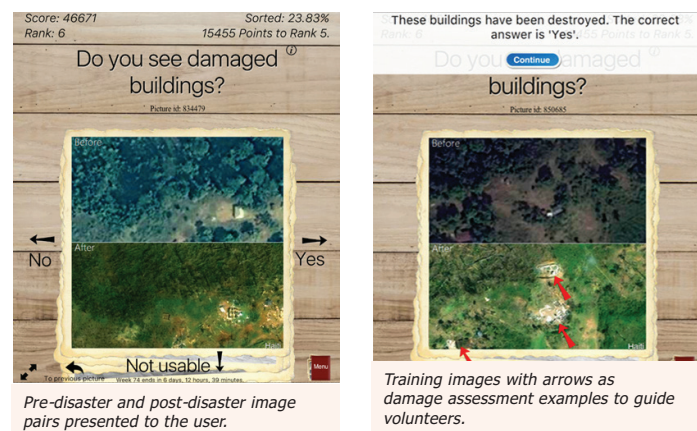
Collaborators

- Imperative Space, UK
- Humanitarian OpenStreetMap Team (HOT), USA
- European Space Agency (ESA)

Further information

- Monitoring deforestation with Picture Pile

- Citizen science campaign to aid disaster response
- Crowdsourcing for post-disaster damage mapping

Playing for a sustainable future

Ecosystems Services and Management

IIASA teamed up with the Organisation for Economic Co-operation and Development (OECD) and the European Commission to test and play The World's Future game—a social simulation game developed by IIASA researchers on the interconnected nature of the Sustainable Development Goals (SDGs). The game sessions provided valuable insights on SDG implementation, while also offering an excellent opportunity for people from different working units and sectors to interact and exchange ideas.

With the adoption of the 2030 Agenda for Sustainable Development and the 17 SDGs, the international community created a comprehensive and indivisible set of goals attaching equal importance to environmental, social, and economic concerns. This acknowledges for the first time that transformation to sustainable and resilient societies cannot happen with a "business as usual", siloed, approach, and that a systems approach is a necessary condition for successful transformation. Translating this awareness into policymaking processes, however, remains a challenge. A full understanding of the interconnected reality of the SDGs remains elusive, and practitioners are seeking robust tools and guidance that can increase awareness and understanding that will eventually make integrated and coherent policymaking common practice.

To meet the challenge, a number of tools were developed to support policymakers and other actors in society in designing, implementing, and supporting coherent and integrated policies in pursuit of these goals and targets, and to consider transboundary and intergenerational impacts. One such tool is a social simulation game called The World's Future: A Sustainable Development Goals Game. The game was developed during the Systems Analysis Forum (SAF) exploratory project, "Systems Thinking for Transformation", that was led by the Ecosystem Services and Management Program (ESM), in collaboration with the Risk and Resilience Program and the Centre for System Solutions. This serious role-play game is based on scientific systems research, and functions as an experiential training and learning playground. The game challenges participants' understanding of sustainability dynamics and their ability to innovate and collaborate towards the global goals. Specifically, it aims to help players deepen their understanding of the complexities of the global system. This includes identifying and acknowledging the interdependency of actions in pursuit of the goals across policies, regions, and time; better understanding synergies, trade-offs, and feedbacks, as pursuing some goals and targets might undermine the achievement of others; as well as the ability to reflect on negotiation patterns, effective communication, and collaboration.

The OECD gaming session took place in June 2017 and was organized with the unit for Policy Coherence for Sustainable Development. The game prototype was played with an interested group of OECD sectoral experts and

Focal Points from OECD member states, who also helped test and further improve the game through their feedback. At the European Commission, two game sessions were organized with the Directorate-General for International Cooperation and Development's Policy and Coherence unit (DG DEVCO A1)–one session for the unit itself, and one session for staff from other DGs. Both sessions took place in Brussels in October 2017.

The World's Future game was very well received by both institutions, and participants agreed that it was a realistic representation of real world situations and challenges. Although many real-world complexities are expressed in the game, it is important to note that the game is not based on any specific national situation. This means that participants will not necessarily be able to draw direct policy conclusions from the game. However, as a capacity building exercise, players can gain multiple insights to clarify, inspire, and offer guidance in terms of policy decisions in their real-life contexts.

In addition to the sessions held at the European Commission and the OECD, many other groups across Europe, including some at the European Forum Alpbach, the National Youth Agency Austria, and the ScienceCenter-Network Austria, also played The World's Future game in 2017.

Feedback from participants

"It is a humbling and eye-opening experience for us as policy writers – to be confronted with the complexity of policy making in action and trying to find sustainable solutions, even in such a simplified version of reality."

"The game helped to get a better overview of how connected the world is and I can now better visualise the different sectors as one big picture. I also don't easily judge actors in different positions anymore, as one learns how difficult it actually is to achieve something together."

"One key take-away for me was an urgent need to better understand real incentives for different stakeholders to implement change in their industries. What makes them change? We don't really seem to know…"

"I got much clearer insight that policy making is actually messy, based on imperfect understanding of the system and incentives, as well as on imperfect information of what others are doing."

Collaborators

- Organisation for Economic Co-operation and Development (OECD): Ebba Dohlman, Senior Advisor, Policy Coherence for Sustainable Development, Office of the Secretary-General

- European Commission: Amalia Garcia-Tharn, DG DEVCO A1 – International Cooperation and Development, Policy and Coherence

- Centre for Systems Solutions (CRS)

Further information

- A Sustainable Development Goals game

Improving projections of future land use and environmental impacts

Earth's ecosystems are being pushed beyond safe limits in terms of freshwater use, biodiversity, and biogeochemical flows. According to researchers at the IIASA Ecosystem Services and Management Program (ESM), existing modeling tools need to be revisited to ensure that they are able to inform policies that can address this multi-faceted problem. To this end, ESM researchers refined the IIASA Global Biosphere Management Model (GLOBIOM) and started developing a flexible and scalable machine learning meta-model for the spatio-temporal downscaling of global crop model outputs.

As part of the Stimulating Innovation for Global monitoring of Agriculture (SIGMA) Horizon 2020 Project, ESM researchers embarked on a project to improve the cropland expansion and intensification process in the GLOBIOM agricultural and forest sector model. This included improving the downscaling functionality of the model to produce spatially explicit, reliable outputs on projected land-use change, and applying the model at the global scale to produce projections of cropland and major cropping systems for future scenarios in 2030 and 2050. In addition, the researchers developed methods to diagnose their impacts on greenhouse gas (GHG) emissions, reactive nitrogen flows, and terrestrial biodiversity.

As a first step, the ESM team improved the expansion and intensification modules of GLOBIOM. They collected new datasets to calibrate and set parameters for the new module functions, using a novel time series method to estimate crop and region specific price elasticities of area, quantity, and yield with a global coverage. Following this, they used the newly estimated elasticities to evaluate the behavior of the latest version of GLOBIOM. This diagnostic, along with additional data sources, and a novel global scale dataset of Environmental Policy Integrated Model (EPIC) crop model simulations (Hypercube), were used to improve the representation of cropland expansion and intensification in GLOBIOM. The team also used an econometric downscaling method for the land use and land use change results of GLOBIOM, where regional results are downscaled significantly. The method is capable of taking into account the uncertainty of existing land use maps, and provides valuable inference over the drivers of high-resolution land use change.
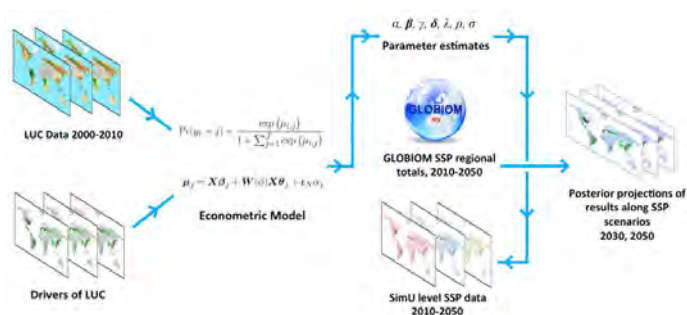

Overview of the GLOBIOM downscaling framework

Based on this new downscaling module, the researchers were able to provide cropland projections for 2030 and 2050 along different Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs).

To assess the environmental impacts of these high resolution land use changes, the team also developed novel methods to translate land cover and land use changes into habitat changes, species richness, and loss of threatened endemic species (in collaboration with ETH Zurich), by integrating a new dataset of estimates of scale water and nitrogen balances using the EPIC crop model. Preliminary results indicate, for example, that by 2050, significant intensification of cropland will increase the amplitude of nitrogen input to cropland and losses to the environment by more than 50%. Future changes in cropland extent will generate a moderate (less than 10%), but robust decrease in the average global species richness and loss of threatened endemic species richness. This implies that without mitigation efforts, the future expansion of cropland will generate additional GHG emissions. Future cropland extension could also amplify the effect of projected increase in cropland intensity in some scenarios, while increased climate change mitigation reduces cropland expansion and could lead to co-benefits for biodiversity.

Apart from the refinement of GLOBIOM, the Agro-Environmental Systems team at ESM also started developing a flexible and resource-efficient machine learning (ML) meta-model that would allow for spatio-temporal downscaling of crop model outputs at a high spatial resolution.

The IIASA-EPIC global gridded crop modeling (GGCM) framework, produces outputs at spatial resolutions that are often too comprehensive for use in regional and local decision making. The EPIC Hypercube dataset for example, provides monthly to annual data on global crop production, crop intensification responses, and associated environmental externalities. In 2017, in a collaboration with the International Maize and Wheat Improvement Center (CIMMYT), the team implemented a number of ML algorithms, namely gradient boosting and random forests, to downscale global EPIC Hypercube simulations of maize yield potential to a finer resolution at the extent of Mexico (project ColClim).

The ML model was tested for downscaling selected agricultural externalities, in addition to crop yields. Since additional data dimensions and environmental predictors are needed for developing a flexible ML meta-model, the team collaborates with the existing GGCM community and its ongoing activities, including the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP), to facilitate this requirement [1][2].

Examples of rain-fed maize yields for the year 2000 from (a) global IIASA-EPIC Hypercube at 0.5×0.5 arc-deg, and (b) corresponding ML predictions for Mexico at 1×1 km.

The ML meta-model provides the means to inform decision-making processes at regional and sub-regional scales

These methodological improvements allow comprehensive quantitative assessments of future land use change and related policies, and will increase the ability of researchers to cooperate both within and outside of IIASA. This work was presented at conferences [3][4] and has led to several publications [5][6][7]. It is also currently contributing to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) process and generating new scenarios, which are expected to lead to high policy impact in 2018.

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- National Institute for Environmental Studies (NIES), Japan
- Tokyo University, Japan

- UN Environment World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, UK
- The Commonwealth Scientific and Industrial Research Organization (CSIRO), Canberra, Australia
- Potsdam Institute for Climate Impact Research (PIK), Germany
- Centre for Hydrology and Ecology (CEH), UK
- New York University, USA
- International Maize and Wheat Improvement Center (CIMMYT), Mexico

Further information

- SIGMA
- GLOBIOM
- EPIC
- Agro-Environmental Systems (AES) Group

IIASA BY PROGRAM

Energy

The way society uses energy gives rise to major environmental, social, and economic challenges. Energy Program research identifies the solution space to energy challenges, analyzes whether current policies are on track to meet policy targets, and examines the interaction between different sectors. A main strength of the program is its ability to understand trade-offs and synergies between multiple policy priorities and objectives in different sectors.

[Program website] [Scientific recognition] [Publications] [Staff] [Events]

Selected highlights

Ensuring a decent standard of living for all

Developing an open source energy model

The climate implications of today's energy policies

Finding solutions to ease pressure on water, land, and energy systems

Objectives

- Continue to develop the program's integrated assessment Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) as a tool for energy policy analysis in collaboration with scientists in IIASA member countries.

- Develop and quantify a new conceptual framework for energy poverty–moving from energy access to a broader definition of energy for human wellbeing.

- Investigate the interplay between global sustainable energy and climate objectives, and national goals, sociopolitical circumstances, and capacities.

- Build on the position of the IIASA Energy Program as a leader in the scientific community coordinating major international research projects, and continue to serve as a hub for important community datasets and services.

- Develop interactive web-based policy tools and hold regular stakeholder workshops that foster the science-policy dialogue on energy sustainability.

- Establish a broad capacity-building platform with key partners from G20 countries (with a focus on the co-benefits of climate and development policies).

- Analyze the interactions between land, water, and energy sectors to identify solutions that meet multiple policy objectives and quantify the cost of implementing multiple Sustainable Development Goals (SDGs).

Ensuring a decent standard of living for all

How much energy growth and what climate impacts are associated with meeting basic human needs? Bottom-up modeling of energy demand requirements in three countries—Brazil, India, and South Africa— shows that current energy supply could provide decent living standards if equitably used. A number of studies by IIASA researchers revealed opportunities for improving living standards while lowering emissions growth.

The Decent Living Energy (DLE) project quantifies the relationship between basic human wellbeing, energy demand, and greenhouse gases. In 2017, the project completed a methodological tool to measure the energy needs for poverty eradication and applied it in Brazil, India, and South Africa to generate policy-relevant insights on the energy needs for poverty eradication in different national contexts. The methodology builds on a conceptualization of material requirements of human wellbeing, or decent living standards [1]. It applies a set of tools from industrial ecology—including multi-region, input-output and lifecycle analysis, and building simulation models—to trace the energy use through the economy, to quantify the energy use associated with the goods and services needed to meet basic needs.

Illustrative energy requirements to provide decent living standards in India and Brazil, showing capital turnover and operating energy. Note: Space conditioning includes hot water production.

These methodological advances have made it possible for researchers to quantify the energy needs for meeting gaps in housing, nutrition, and health and education [2][3], and to reveal limitations in demand-side modeling in integrated assessment research [4].

DLE also investigated past trends in achieving living standards and related energy consumption patterns [5][6][7]. This research shows that income is a crude predictor of household appliance uptake in emerging economies, and that affordability and culture play a significant role. Although living standards have improved across the world due to growing income, clean cooking and improved sanitation consistently lag behind electricity and improved water provision. The researchers found that these gaps affect women's health in particular.

The energy needs for meeting the gaps in living standards are dominated by the construction of safe homes and transport infrastructure to provide mobility to all [3][8]. What is particularly important for achieving the Sustainable Development Goals (SDGs) is that basic needs, such as food, education, health care, and basic utilities, are relatively inexpensive in energy terms. Another piece of good news is that micronutrient deficiencies in India, which affects over two-thirds of Indians, can be reduced by shifting cereal consumption from rice to coarse cereals, which would also reduce greenhouse gas emissions [9]. This work was presented to policymakers in India who are evaluating alternative pricing policies for cereals.

Going forward, this work will facilitate a country wise assessment of the synergies between mitigating climate change and achieving other SDGs. Additionally, it will provide a foundation for future research on building energy demand projections from end-use services, rather than from GDP. DLE research outcomes generate policy insights on the synergies between energy planning, climate mitigation, and social development goals.

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Further information

- Project website

Developing an open source energy model

Energy

The IIASA Energy Program (ENE) has developed a new generation of its modeling platform MESSAGEix, which is now available under an open source license. The model is used for research applications, as well as for capacity building in IIASA member countries and teaching at universities.

The MESSAGE Integrated Assessment Model developed by ENE has been a central tool in energy-environment-economy systems analysis in the global scientific- and policy arena. It plays a major role in the Intergovernmental Panel on Climate Change (IPCC) assessment reports; it provided marker scenarios of the Representative Concentration Pathways and the Shared Socioeconomic Pathways; and underpinned the analysis of the Global Energy Assessment.

To stay at the frontier of model development, numerical models of human and earth systems need to support higher spatial and temporal resolution, better integrate diverse data sources and methodologies, and become more open and transparent. To deal with these challenges, ENE developed a new modeling platform, called MESSAGEix, which is available under an open source license that facilitates external collaboration and joint model development. This new integrated assessment-modeling platform consists of four building blocks, including an open-source General Algebraic Modeling System (GAMS) implementation of the MESSAGE energy system model integrated with the MACRO economic model; a Java/database version-controlled data management repository; user interfaces for both the

scientific programming languages Python and R for efficient input data and results processing workflows; and a web-based user interface for model/scenario management and intuitive drag-and-drop visualization of results.

The framework aims for the highest level of openness of scientific analysis, bridging the need for transparency with efficient data processing and powerful numerical solvers. The platform is geared toward easy integration of data sources and models across disciplines, spatial scales, and temporal disaggregation levels. All tools apply best practice in collaborative software development and comprehensive documentation of all building blocks, while scripts are generated directly from the GAMS equations and the Java/Python/R source code.

At present, MESSAGEix is being used for building new integrated basin-level modeling tools to address the challenges of the water-energy-land nexus as part of the cross-cutting Integrated Solutions for Water, Energy, and Land (ISWEL) project. The model is also already actively being used by several research organizations in IIASA member countries, for example, the University of Rio de Janeiro in Brazil and TU Munich in Germany. ENE is also supporting government organizations in member countries to develop energy modeling capacity based on the MESSAGEix model, including the National Institution for Transforming India (NITI Aayog) think tank in India and the Ministry of National Infrastructures, Energy, and Water Resources in Israel. Finally, in collaboration with universities, MESSAGEix is used for teaching energy and integrated assessment modeling, at, among others, TU Wien in Austria and Politechnico di Milano in Italy. For this purpose, ENE researchers have developed training materials, including a number of tutorials that are part of the MESSAGEix release.

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Components and their interlinkages in the ix modeling platform [1]: web-based user interface, scientific programming interface, modeling platform, database backend, implementation of the MESSAGEix mathematical model formulation.

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Further information

- Model documentation
- Model code (GitHub)

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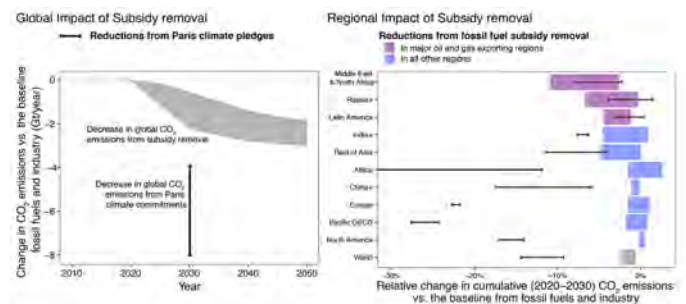# The climate implications of today's energy policies

Energy

What do today's energy policies add up to and how do they differ by region? Although climate change is a global problem, the policies to address it will be enacted at the national and local level. We need to understand the emissions implications of today's energy policies to know if we are on the right track to meet global climate targets and what needs to be clarified within policy pledges to reduce uncertainty. Two recent papers from the IIASA Energy Program further our understanding of today's policy proposals and their regional implications.

A study published in *Nature Communications* [1], carried out the first comprehensive uncertainty assessment of countries' national climate pledges put forward during the Paris climate agreement (known as nationally determined contributions or NDCs) at both the global and regional scale. It robustly shows that current proposals are both imprecise and inadequate. The vagueness in pledges results in a large spread in what emission levels can be expected for the year 2030, which even if strengthened afterwards would fail to achieve the ambitions of the Paris Agreement's temperature goal. The study identified China and India as two regions that contribute most to the overall uncertainty. As international negotiations are currently under way to define future rules for the formulation of and reporting on national pledges under the Paris Agreement, this study proposes several improvements to the NDCs reporting process, which would reduce overall uncertainty and increase accountability within international climate policy based on the most up-to-date science.

Another study led by IIASA researchers, published in *Nature* [2], looked into the global and regional effects of removing fossil fuel subsidies. It found that although fossil fuel subsidies amount to hundreds of billions of dollars, removing them would only slightly slow the growth of CO2 emissions, with the result that they would only be 1–5% lower by 2030 than if subsidies had been maintained. This equates to 0.5–2 gigatonnes (Gt/year) of CO2 by 2030–significantly less than the voluntary climate pledges made under the Paris Agreement–which add up to 4-8 Gt/year and are themselves not enough to limit warming to 2°C. Although the global effect on emissions is low, the impact varies between regions. The largest effects of removing subsidies were found in regions that export oil and gas, such as Latin America, the Middle East, North Africa, and Russia. In these regions, the emissions savings caused by subsidy removal would either equal or exceed their climate pledges. It is also these oil and gas exporting regions whose government budgets are most strained under low oil prices and for whom subsidy removal would thus be a welcome relief.

The regional differences highlight one very important aspect of subsidy removal that needs to be taken into consideration: the impacts on the poor. Fortunately, the highest numbers of poor people are concentrated in the regions where removal of subsidies will have the weakest effect on

CO2 emissions. Removing subsidies in richer oil and gas exporting regions would therefore provide significantly greater emissions savings and have a less detrimental impact on the poor.

In 2017, Energy Program research outreach fed directly into several international and regional policy processes, as well as into the broader scientific community. The insights of the *Nature Communications* paper were featured in the UN Environment Programme Emissions Gap Report [3], which provides an annual overview of the state of the science on climate action and in which the IIASA Energy Program has been taking up leading roles. Energy Program researchers were invited to present their insights at the UN Framework Convention on Climate Change Research Dialogue, the EU Issue Group on NDCs, and at a special session dedicated to the implications of the Paris Agreement at the Fall Meeting of the American Geophysical Union, the world's largest geoscience conference. The *Nature* paper was also covered by several news outlets including *Scientific American*.

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Further information

- Removing fossil fuel subsidies
- Nexus blog

Finding solutions to ease pressure on water, land, and energy systems

Energy

The IIASA Energy Program (ENE) is pioneering systems analysis tools for analyzing the water-energy-land nexus. Water, land, and energy systems all face pressures. By analyzing interactions between these sectors, researchers can identify multi-sector vulnerabilities to global environmental change, solutions that meet multiple policy objectives, and quantify the cost of implementing multiple Sustainable Development Goals (SDGs).

ENE continues to develop its well-established capabilities and expertise for understanding the complexities and linkages of the energy, water, and land nexus. A large collaboration, led by researchers from the program has developed a comprehensive framework to assess these interactions under different climate change and socioeconomic development scenarios [1]. Working with scientists from other IIASA programs as part of the Integrated Solutions for Water, Energy, and Land (ISWEL) project, the analysis uses a set of spatial indicators across the energy, water, and land sectors, to identify both sectoral and multi-sector 'hotspots'–or areas that will face multiple climate and development challenges. The first results revealed that although global hotspot exposure is limited to a relatively small fraction of global land area, the risks to human populations would be large. The increase in exposed population to hotspots almost doubles (from 1.5 to 2.7 billion people) when moving from a global mean temperature increase of 1.5°C to 2.0°C, and increases similarly (from 2.7 to 4.6 billion people) when moving from 2.0°C to 3.0°C.

This analysis focuses on a dimension of climate impacts that is often missing from global assessments–the vulnerability of exposed populations. By using new high-resolution projections of future income levels, this work provides critical guidance into the regions where poverty eradication strategies would provide the largest reduction in vulnerability to climate change.

Other work undertaken within the ISWEL project, estimates the investment required for achieving clean water and sanitation (SDG6) to be between 1.1 to 1.6 trillion US$ per year by 2030 and between 1.5 and 2.1 trillion US$ by 2070 [2]. The costs grow by an estimated 2 to 6% when combined with energy decarbonization pathways consistent with a 1.5°C climate target due to higher electricity prices under decarbonization and a growing share of electricity-intensive water resources. The analysis reveals that scenarios involving transformation towards sustainable water consumption patterns and energy-efficient water technologies largely avoid increasing water supply costs under combined policy objectives. The methodological developments to do this analysis and develop a reduced-form representation of the water supply sector into the MESSAGE-GLOBIOM integrated assessment model can now also be used for other SDG analysis over different sectors,

The nature of the interactions between SDG7 (energy) and the non-energy SDGs. The relationships may be either positive (left panel) or negative (right panel) to differing degrees. [3]

timeframes, and geographic scales.

Working with the International Council for Science, ENE researchers also pioneered a system literature analysis to understand whether different SDGs reinforce, or conflict with each other. Using the goals related to "Affordable and Clean Energy" (SDG7) and "Climate Action" (SDG13) as an entry point, the research found that positive interactions far outweigh negative ones, both in number and magnitude [3]. In other words, efforts to achieve one SDG are likely to help achieve one of the others. Another key finding identified energy as one of the most influential SDGs, while meeting the targets related to "Affordable and Clean Energy" were found to have enabling, and in most cases, reinforcing benefits across all other SDGs. Efforts to increase renewable energy sources, for example, reinforces the SDGs on health and wellbeing by ensuring cleaner air and water. On the other hand, if meeting the "Clean Energy" SDG leads to growth in bioenergy, this could compromise the "Zero Hunger" SDG, as there is evidence that bioenergy and food prices are linked. Nonetheless, the scientists agree that achieving "Affordable and Clean Energy" would have enabling and reinforcing benefits for all other SDGs.

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Evolution and Ecology

Adaptations are key to understanding living systems, especially in these times of global change. In social systems, behaviors adapt through individual and collective learning. In biological systems, genes adapt through evolution under natural and anthropogenic selection pressures. To address these universal challenges in managing the biosphere, the Evolution and Ecology Program devises, analyzes, and calibrates models of complex adaptive systems.

Program website   Scientific recognition   Publications   Staff   Events

Selected highlights

Artificial reefs breathe new life into ecosystems

Getting to grips with evolutionary fisheries science

Shedding light on vegetation dynamics

Understanding armed conflicts

Objectives

- Develop new tools for integrating biological, social, and economic dimensions in fisheries assessments.
- Enrich game-theoretical models for common-good management with real-world complexities including bounded rationality, social heterogeneity, cultural dispositions, and institutional incentives.
- Help launch the next generation of dynamic vegetation models.
- Contribute to reconciling polarized conflicts by advancing quantitative stakeholder methods in fisheries management.
- Coordinate an international consortium defining protocols for integrating evolutionary change in annual fisheries assessments.
- Build awareness of dangerous biases in recognizing systemic risks.

Artificial reefs breathe new life into ecosystems

Evolution and Ecology

Artificial reefs are becoming increasingly popular as a means of restoring and protecting coastal ecosystems and fishery resources. But do they work? A new study from the IIASA Evolution and Ecology Program suggests that the answer is a qualified yes.

Artificial reefs are man-made structures deployed on the sea floor, ranging from decommissioned vessels to purpose-built concrete structures. An artificial reef can provide new habitat for both juvenile and adult fish, thereby helping local populations to increase in abundance. At the same time, artificial reefs can reduce fishing pressures, because they restrict the types of fishing gear that can be used in their immediate vicinity. In particular, reefs hinder bottom trawling–an extremely efficient fishing method where conditions permit–as fishers run the risk of their expensive gear becoming entangled with the reef. Artificial reefs can also benefit tourism if they become places where divers can easily observe an abundance of diverse marine life.

Are artificial reefs worth the effort? It is well documented that artificial reefs indeed lead to local increases in many types of fish and shellfish. It is however more difficult to establish how much such increases are due to the enhanced productivity of local species, or because of the movement of individuals to the new reef from nearby areas–in the latter case, there is no increase in their overall regional abundance. Whether artificial reefs thus make economic sense remains uncertain, with some studies suggesting positive effects, while others have found no effects.

The Chinese government has invested heavily in artificial reefs [1]. In Shandong, a coastal province in eastern China bordering the Yellow Sea and the East China Sea, 170 artificial reef projects have been completed. The new reefs cover a total area of 150 square kilometers, that is, the equivalent of 21,000 football fields. The purposes of these reefs are manifold and include rebuilding fisheries, providing habitat for sea-ranching operations, and creating opportunities for tourism and recreational fisheries [2].

In this study, IIASA researchers assessed whether artificial reefs brought economic benefits in terms of increased fisheries revenues. The data were

Fat greenling (Hexagrammos otakii) is the most abundant species in the artificial reef sites. Source: Wikimedia Commons (CC-BY-SA-2.5).

Artificial reefs in Shandong, China, have a positive effect on both the revenue and the catch per unit effort for an average fish species (right half), but not when revenues and catches are aggregated over all species (left half). The difference occurs because some of the dominant species on the control sites do not benefit from the artificial reefs, overshadowing the positive effect on many sub-dominant species. The vertical lines indicate the 95% confidence intervals.
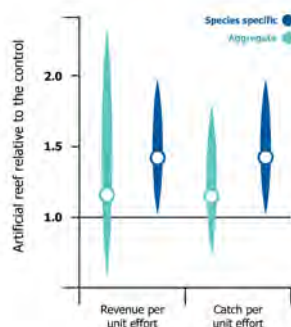
obtained from three artificial reef sites and nearby control sites in Shandong, and monitored by researchers from the College of Fisheries of the Ocean University of China. In terms of total revenues across all species, the researchers found no consistent differences between reef sites and control sites. However, when the data were analyzed at species level, different results became evident, with both catch and revenue obtained with the same effort being about 40% higher at the reef sites than at the control sites [2].

According to the researchers, the fact that the two types of analyses led to different conclusions is not surprising, as they address different questions. For the aggregate analysis examining total revenues, the results were largely determined by the responses of the dominant species that make up the bulk of the catches.

In particular, the species that dominated the control sites did not benefit from the artificial reefs, or were even negatively affected, hence, an overall effect could not be found. In contrast, when the researchers analyzed the data so that all species were given equal weight (without considering rare species), the sub-dominant species also became influential for the results. Among these, many species benefited from the artificial reefs [2].

This study highlights the need to be specific when asking sustainability questions such as what the benefits of artificial reefs are for fisheries. Although it is legitimate to focus on overall performance and/or average effects across species, it must be recognized that these represent distinct criteria that should not be confused when planning reef projects and assessing their outcomes.

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Further information

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Getting to grips with evolutionary fisheries science

The IIASA Evolution and Ecology Program has played an internationally leading role in bringing attention to the evolutionary consequences of exploiting the world's fish stocks. Fishing not only affects the numbers of fish, but also their heritable characteristics. While most examples of such evolutionary changes concern shifts in how long organisms wait before starting to reproduce, a new study on Atlantic cod shows that evolutionary responses to fishing also affect other aspects of reproductive behavior.

Fishing is an important source of food and nutrition for many people around the globe, especially in the developing world. Naturally, fish see only the other side of that coin—elevated mortality. It is widely acknowledged that even sustainable fishing practices inevitably reduce the abundance of fish populations. Until recently, an appreciation that fishing, when sustained over many generations, also affects the inherited characteristics of fish, was largely absent and is still developing. The Evolution and Ecology Program at IIASA has been assembling empirical evidence and developing the theoretical understanding required for finding the best ways to minimize unwanted evolutionary changes.

A very effective adaptation of fish to high fishing pressures is earlier maturation and the bulk of empirical evidence on the evolutionary effects of fishing confirms this. However, other traits are also likely to be important and the predominance of studies on maturation may in fact have more to do with the scarcity of data on evolutionary responses in other traits [1].

In the waters around Newfoundland in eastern Canada, fishing Atlantic cod has been the lifeline of local communities for centuries. The Department of Fisheries and Oceans (DFO) Canada has been conducting regular surveys on cod stocks since the mid-1980s, providing data to understand how cod populations have been developing. These data, on which the Evolution and Ecology Program have now collaboratively built with DFO scientists, allow researchers to study changes in the life-history characteristics of these stocks.

The cod stocks off Newfoundland are infamous for the collapse that led to the closing of cod fisheries in 1992, with full recovery from this disaster still pending. During the period leading up to the collapse, the size at which cod matured was gradually declining. Previous studies have shown that this decline was likely an evolutionary response to continued heavy fishing, as well as an indication of dangerously high fishing pressure, which could have served as a warning signal of the forthcoming collapse, had these analyses been available then [2]. Similar changes have been documented in numerous other cod stocks [1].

According to evolutionary theory, it is often advantageous for fish to invest more into their current round of reproduction if their chances of surviving to spawn again later are slim. This means that one might expect to observe larger reproductive organs (gonads) in the affected species. Fortunately, the DFO scientists measured the weights of gonads across large numbers of specimens, which offered a rare opportunity to test this theory [3].

Trends in relative gonad size of females (left column) and males (right column) for three stocks of Atlantic cod off Newfoundland (labeled 3L, 3NO, and 3Ps). In each panel, the blue curves show the estimated stock biomasses (right vertical axes). The two other curves show the model-predicted time trends of reproductive investments (measured by the gonadosomatic index GSI, that is, the ratio of gonad weight and gutted weight; left vertical axes) for the best models describing the data for the full time series (orange diamonds), or for the shorter period for which stock-biomass estimates are available (black crosses).

The researchers found that male cod met their prediction: their relative gonad weights were increasing during the period when fishing pressure was high. Moreover, these trends levelled off, or even reversed after fishing moratoria reduced fishing pressure, which is the predicted pattern if fishing was indeed the driving force behind these changes. However, an analogous pattern is not evident in female cod: their gonad weights were stable or even slightly declining, despite the theoretical predictions. The researchers found this even more surprising, given that gonad weight is commonly considered more important for the reproductive success of female cod than of male cod [3].

The reasons for the differences in the results for male and female cod are not yet properly understood. A possible explanation is the higher temporal variability in female gonad weights during the spawning seasons, making them a rather imprecise measure of the underlying energetic investments into reproduction. In addition, the results suggest that sperm production is more important for the reproductive success of male cod than previously appreciated.

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Further information

- Evolutionarily Sustainable Consumption

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Shedding light on vegetation dynamics

Plants are of central importance to terrestrial ecosystems and play a key role in the global carbon cycle. In 2017, the IIASA Evolution and Ecology Program showed how the inclusion of evolutionary and eco-physiological principles enables improved vegetation models.

Evolution and Ecology

Hundreds of thousands of species of plants currently cover the surface of the earth. They are essential for terrestrial ecosystems and the ecosystem services they provide. By producing oxygen while absorbing atmospheric carbon dioxide, plants form an integral part of the global carbon cycle. With human activities now rapidly changing the conditions to which plant species are adapted, there is an urgent need to understand how changing environmental conditions will affect vegetation cover across the globe.

Broadly speaking, current models that aim to predict plant diversity fall into either of two classes. These are neutral models of biodiversity that predict vegetation structure by assuming that community composition arises through random processes, or niche-based models that predict vegetation structure by assuming competition between plant species. Until now, only the neutral models have been able to give reasonable predictions of species diversity, with the niche-based models typically giving rise to only a few coexisting species.

To show how enhanced biological realism can improve predictions of plant diversity and potentially reconcile these two approaches, researchers from the Evolution and Ecology Program developed an eco-evolutionary vegetation model that builds on established eco-physiological and evolutionary principles [1]. By moving beyond the often simplistic assumptions of traditional niche-based models, the study showed how plant diversity can be predicted from knowledge of local environmental conditions. Moreover, by accounting for evolution in two important functional traits, a large neutral range of trait combinations emerges across which species have equal fitness, arguably reconciling neutral and niche-based theory.

As the compositions of plant communities arise intrinsically from the model, rather than being assumed from the outset, the novel approach taken in this study (i.e., working from eco-evolutionary first principles) has the potential to improve species-conservation efforts, land-use policies, and forest-management practices. In addition, it can also help to improve contemporary dynamic global vegetation models that are used to predict the impacts of global and regional climate change. The potential value is especially large for improving predictions of future vegetation structures under environmental conditions that do not currently exist anywhere on earth. The IIASA cross-cutting project on Dynamic vegetation models: The next generation is capitalizing on these opportunities.

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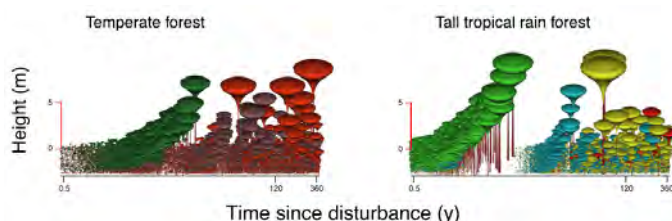
Examples of successional vegetation dynamics under two different environmental settings, corresponding to temperate forests (left panel) and tropical rain forests (right panel). Early fast-growing species quickly establish themselves following a disturbance and are later outcompeted by slower-growing, more efficient species. All shown species—or plant functional types—are not just assumed from the outset, but emerge intrinsically as a predictive and empirically testable result of the model.

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- Eco-evolutionary Vegetation Modeling and Management
- Dynamic vegetation models: The next generation
- How nature creates forest diversity

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Understanding armed conflicts

Armed conflicts remain widespread around the globe, yet their dynamics are poorly understood. The recent introduction and analysis of a simple model enables basic insights into how military characteristics and recruitment policies affect the dynamics of these situations. In particular, the model shows when stationary and periodic stalemates are possible and how initial conditions and interventions influence the outcome of a conflict.

Owing to the prevalence and complex nature of armed conflicts, the interest in mathematical models that endeavor to understand them has increased in the last decades. Armed conflicts often involve more than two groups, which typically differ in their military characteristics and recruitment policies. Consequently, traditional descriptive conceptual models are of little help.

The new model has already produced interesting results for a simple case–an armed conflict between a governmental group and a rebel group [1]. The model indicates that an eradication of the rebel group cannot always be guaranteed, but that, instead, stalemates arise that can be stationary or periodic. Secondly, the model shows how outcomes are contingent on initial conditions. Lastly, when a conflict is trapped in a periodic stalemate, the model also allows the groups involved to determine when stepping up their efforts would have maximum effect.

Example of dynamics that may result in a simple model of armed conflict among three groups. One group has the military characteristics and recruitment policies of a governmental army (red), while the other two groups are typical of rebels (green and blue). Over time (horizontal axis), the abundance of different fighters involved in this conflict (vertical axes) changes. At the time indicated by the black arrow, one of the rebel groups (blue) is attacked and eradicated, leading to a resurgence of the other rebel group (green) and its subsequent periodic stalemate with the governmental army (red).

It is generally believed that the outcome of complex conflicts involving rebels and governmental groups cannot be predicted, because data are generally too scarce and unreliable. The results obtained with the new model show that the truth may be even less convenient, as the dynamics among the fighting groups can be extremely sensitive to initial conditions and parameter values [1]. This suggests that the outcome of a conflict may be practically unpredictable,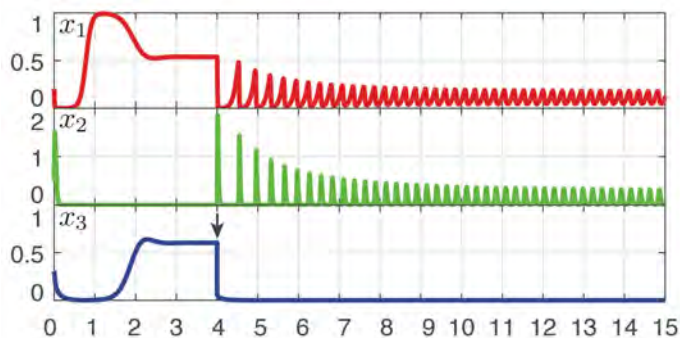 even if very rich data sets were available. This finding, which is common to many complex adaptive systems, challenges the enthusiasm toward data-driven decision making.

According to the researchers, the results obtained so far have proven to be robust. The same results are recovered in a simplified model in which governmental groups are assumed to be purely defensive (i.e., their recruitment depends only on sustained injuries), while rebel groups are supposed to be purely fanatic (i.e., their recruitment depends only on inflicted injuries).

Further research is needed to address important open questions. Some of these are more academic in nature, such as whether armed conflicts exhibit deterministic chaos, peak-to-peak dynamics, and chaotic intermittence, while others are of greater relevance to decision makers, for example, how the models can describe the effects of temporary coalitions or of changes in power and intelligence. Answering these questions requires combining a deep knowledge of case studies with expertise in the theory of nonlinear dynamical systems.

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Risk and Resilience

The major risks facing the world—from extreme events, to food and water security, to climate change—are complex, systemic, and far-reaching. Building on a history of ground-breaking research, the Risk and Resilience Program is well positioned to take an interdisciplinary, systems perspective on risk policy problems. The program aims to help transform the way societies manage risks while confronting the global trends amplifying them. There is also a strong emphasis on enhancing the resilience of vulnerable communities, countries, and regions.

Program website   Scientific recognition   Publications   Staff   Events

Selected highlights

Informing policy decisions when disaster strikes

Global breadbaskets: Possibilities for risk pooling

Operationalizing the Loss and Damage Mechanism

In search of perfect foresight

Objectives

- Develop the next generation of the Risk and Resilience Program's Catastrophe Simulation Model to incorporate interdependent risks and longer-term scenarios, with applications to flood resilience, the Loss and Damage Mechanism, UN Sustainable Development Goals, and other risk topics.

- Co-develop innovative resilience measurements, and management methods and tools as part of the Flood Resilience Alliance.

- Expand into new areas of risk research exploring contributions to the energy-water-nexus and how to achieve the Sustainable Development Goals.

- Further develop and apply the Risk and Resilience Program's participatory process design incorporating the heterogeneity of stakeholder views, multi-criteria analysis, and social media applications.

- Initiate and develop an extensive research network informing policymakers on how to address the loss and damage associated with the impacts of climate change, particularly in vulnerable developing countries.

- Establish a broad, capacity-building platform on disaster risk management and resilience to serve relevant institutions in IIASA member countries.

Informing policy decisions when disaster strikes

Natural disasters in low-income regions have far-reaching impacts on all levels of society. A simulation framework developed by IIASA researchers can help policymakers to come up with informed short-term policies in an environment where they have limited resources and data to deal with issues like population displacement and food shortages, in a short timeframe.
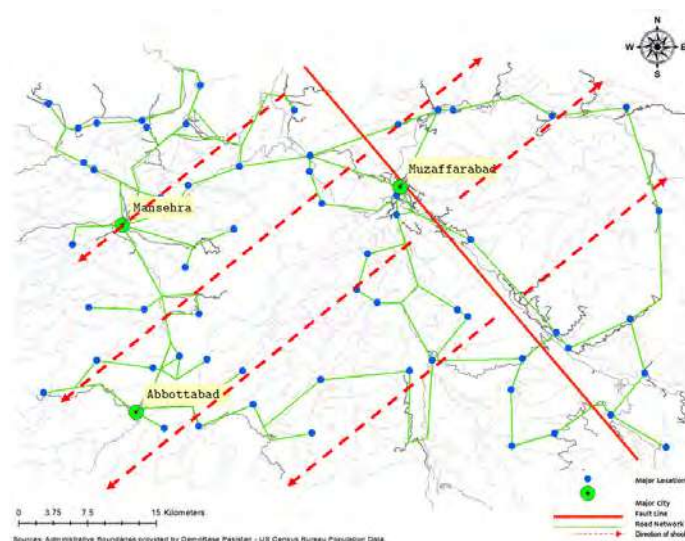
The effects of natural disasters in low-income regions (i.e., higher internal migration and low consumption levels) are the result of market failures that force the affected population to respond and adapt to the shock they face. In an environment with multiple locations and independent, but inter-connected markets, these transitions quickly become complex due to the feedback loops between the different market aspects.

To capture these continuously evolving interactions, researchers from the Risk and Resilience Program employed a model to analyze natural disaster-like shocks in low-income regions. They defined it in terms of six modules namely, production, consumption, buying, selling, income, and migration. The interaction between these modules produces a complete, closed economic system, allowing them to track the impact of a shock to one part of an economic region on the rest of the region. The aim of the model is to track how population distribution, income, and consumption levels evolve over time and in a defined geometrical space, in order to identify high priority issues such as food insecure populations.

The researchers applied their model to data from the 2005 earthquake in northern Pakistan. The region faced catastrophic losses and high levels of displacement in a short time span, and the accompanying labor, and goods market disruptions, resulted in a high level of food insecurity.

A geographic information system (GIS) map of the region was used as the physical environment in which the model of the artificial economy was situated. This included important features key to the functioning of the model, such as the precise locations of villages, cities, and roads. The model was calibrated to pre-crisis trends, and shocked using distance-based output and labor loss functions to replicate the impact of the earthquake. The model outputs showed plausible patterns, such as disruptions to the flow of goods, and population loss resulting in market imbalances. These results highlight patterns of consumption losses in specific locations over time, thus allowing for better identification of the most vulnerable hotspots of the earthquake-affected region.

The simulation framework presented by the researchers goes beyond existing modeling efforts that usually deal with macroeconomic long-term loss estimates. Policymakers will be able to use the information generated to devise informed short-term policies in environments where data is virtually non-existent, policy response is time-dependent, and resources are limited.

Propagation of shock in the 2005 Pakistan earthquake. Small dots represent villages and large dots represent cities. Green lines show the road networks. The solid red lines represent the fault line, and the dotted red lines the direction of the earthquake shock.

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Further information

• Risk management and adaptation

Global breadbaskets: Possibilities for risk pooling

Risk and Resilience

Simultaneous crop losses in different parts of the world can pose a serious risk to global food security. However, little is currently known about the spatial dependency of crop yield losses between global breadbaskets. In a recent study, IIASA researchers focused on wheat yields to identify systemic risk within specific regions.

The term breadbasket is commonly used to describe an area with highly arable land that produces food–particularly grains–to feed the people of its own country, as well as for export to other places. The increasing global interconnectivity and mutual interdependence of economic- and ecological systems can amplify the vulnerability and risk of disasters. The global food system is a good example of the effects of this increased interdependence and the possibility of systemic risk.

Owing to the globalization of the grain market, a food shock due to drought, or other natural disasters in one or more major food producing areas, can lead to a significant increase in world food prices, and might threaten food security, particularly in poorer countries. This especially applies in the case of extreme events, where one or more breadbaskets are experiencing far below average yields.

Without the necessary information, risk management approaches cannot be applied and vulnerability to extremes may remain high, or even increase around the world in the future. The Risk and Resilience Program tackled both these issues from an empirical perspective, focusing on wheat yield.

The global wheat breadbaskets.

The researchers estimated the interdependencies between historically observed wheat yield deviations in five breadbaskets: Argentina, Australia, China, India, and the United States. They made use of copula approaches to describe the dependence between variables. In doing so, they were able to attach probabilities to interregional, as well as global yield losses. To increase the robustness of their results, they applied three different methods for constructing multivariate copulas, namely R-vine copulas, ordered coupling using a minimax approach and Gaussian copulas, and hierarchical structuring.
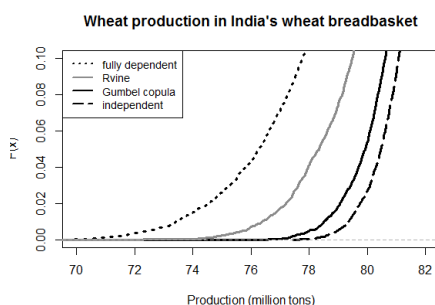
In the case of the Indian breadbasket with today's average wheat, the use of multiple structuring methods revealed differing results. With a probability of 5% or a 20-year return period, for example, the production in the Indian breadbaskets will be 76.1 million tons if the breadbaskets were fully dependent, 78.5 million tons using the R-vine approach, 79.1 million tons applying a structured copula, and 80.5 million tons if correlations between the states are not considered.

These results show that if correlations between wheat yields within the breadbaskets are not considered in risk analysis, the risk of production losses are underestimated. Using the example above, that would imply that the risk of a production of 80.5 million tons is more than three times higher, assuming that all states are independent compared to the R-vine curve. This is important for crop insurance schemes and agricultural policy decisions.

Wheat production in India's wheat breadbasket

Production curves up to the lower 10th percentile of the production distribution for the Indian breadbasket comparing with minimax structured copula using Gaussian copulas and an R-vine with the independent and fully dependent case with today's average production levels.

On a global scale, however, notwithstanding evidence of global climatic teleconnections that may influence crop production, the researchers demonstrated that wheat production losses are independent between global breadbaskets. This strengthens the case for interregional risk pooling strategies, which could in turn decrease the post-disaster liabilities of governments and international donors.

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Further information

• Risk analysis and modeling

IIASA BY PROGRAM

Operationalizing the Loss and Damage Mechanism

With the impacts of climate change already being felt across the globe, it is imperative to manage and avoid further irreversible loss and intolerable damage. According to IIASA researchers, adaptive learning linked to climate risk management can help overcome substantial scientific and political challenges.

Despite the Paris Agreement's call for limiting global warming to well below 2°C above pre-industrial levels, current greenhouse gas emission reduction pledges and mitigation efforts are likely to lead to significantly higher levels of warming. This will likely intensify already significant impacts on the world's climate. Seen from this perspective, another important outcome of the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) was the full endorsement of the Warsaw International Mechanism for Loss and Damage (L&D). To deal with these impacts, policymakers, practitioners, and members of civil society are increasingly advocating pursuing a climate risk management (CRM) strategy.

Such a strategy would entail comprehensively managing existing and future climate-related risks, including limiting their adverse impacts on the natural structure and functioning of ecosystems, and the ability of countries to pursue sustainable development pathways. This would include comprehensively reducing, preparing for, and financing climate-related risk, while tackling the underlying risk drivers, such as climate-related and socioeconomic factors.

This imperative becomes particularly challenging when focusing on those impacts that cannot, or will not, be avoided through mitigation and adaptation, thus causing irreversible loss and residual damage. Yet, the question remains how to implement action on climate-related risks today and in the future given a number of risk-analytical and sociopolitical challenges.

A number of challenges comprise the large uncertainty regarding potential future impacts of climate change at global, regional, and local levels. These include the attribution of loss and damage from specific climate-related disasters to climate change; important questions regarding distributive and compensatory justice; and dealing with non-economic losses such as impacts on ecosystems, health, security, biodiversity, and loss of cultural identity.

To address these issues, IIASA researchers from the Risk and Resilience Program suggest a transdisciplinary dynamic framework building on adaptive learning theory as applied to climate change through the concept of iterative CRM. This concept holds great potential for addressing these challenges and the remittance of L&D.

The researchers examined climate-related risks according to the Intergovernmental Panel on Climate Change's regional assessment for the case of small-island states. The left side of the figure depicts the part of risk that can be managed by conventional climate adaptation and disaster risk reduction (blue green arrows), novel transformative loss and damage measures (white arrows), or curative L&D measures (black arrows). On the right, a framework to tackle increasing climate-related risks is shown.

According to the researchers, in the short term, the incremental adjustment process consists of a number of steps, the first of which entails monitoring existing instruments, new scientific evidence on climate change, natural hazard data, loss databases, the climate signal, and stakeholder perceptions. The second step comprises a model-based analysis of climate-related sudden onset risks and slow-onset processes, acknowledging the uncertainties associated with climate change. Step three involves the integrated appraisal of the new normal, and the modeling of results according to public and private coping capacities, taking into account economic loss and damage, non-economic impacts and risks, and justice considerations. The final step in the process entails the implementation, or update of risk management instruments according to different layers of risk, which requires decision criteria under uncertainty, bearing multiple dividends in mind. Embedding this process in a learning loop framework allows for fundamental and transformative adjustments to current, largely reactive disaster management processes, as well as employing mental and analytical models in the medium to long-term.

The study concluded that, by addressing existing climate variability and extreme weather events in the short term, a CRM-type framework for L&D could kick start the operationalization of actions on Loss and Damage and circumvent a stalemate in the political process. At the same time, by dynamically mainstreaming climate change into L&D practice as new scientific evidence emerges, the role of humans in increasing climate-related risks will not be neglected in the medium to long-term. This may send a powerful message to policymakers in the mitigation domain to work together to meet the Paris Agreement's ambitious temperature targets.

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Further information

- Loss and Damage
- ON THE BLOG: How to kick-start proactive management of climate-related disasters

IIASA BY PROGRAM

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In search of perfect foresight

The failure to foresee the catastrophic earthquake, tsunami, and nuclear accident of 2011 was seen by many as a fundamental shortcoming of disaster risk science in Japan. In light of this, the use of scientific knowledge came under renewed scrutiny. Debates continue over an appropriate role of 'evidence-based policy' in earthquake and tsunami risk reduction.

IIASA researchers reviewed publicly available documents on expert committee discussions and scientific articles, to identify continuities and changes observed with regard to the use of scientific knowledge in Japan's disaster risk management.

They found that, while diverse professional opinions on the root causes of their failures were expressed, these generally converge into two interpretations.

The first interpretation—which the researchers call 'the failure of science' perspective—primarily perceived the heart of the issue to be the lack of scientific capacity. According to this view, scientific understanding of the underlying hazards was insufficient, and the disaster risk management (DRM) system, which was designed based on limited knowledge, led to catastrophic failures. Accordingly, options feeding into solutions prescribed by this perspective were also technical and scientific in nature.

The second interpretation—which they termed 'the failure of science-policy institutions' perspective—contended that the root causes stemmed more fundamentally from issues of science-policy processes. In other words, how the country's earthquake and tsunami scientific research agendas were formulated to provide solutions to the threats posed by these hazards. According to this perspective, the sense of urgency created by an imminent threat of major earthquakes and tsunamis, together with unfounded faith in the ability of science to deliver solutions, led to the silencing of open debate and constructive skepticism. The outcome was an eventual misapplication of science in the formulation of DRM policy. The solution prescribed included a major rethink and further engagement of the scientific community in DRM policymaking in the country.

According to the researchers, in general, the prior influence of cognitive biases, such as an over-reliance on documented risks, has been largely recognized, and increased attention is now being paid to the incorporation of less documented, but known risks. This has led to upward adjustments in estimated damages from future risks, and recognition of the need for further strengthening DRM policy. Simultaneously, there remains significant continuity in the way scientific knowledge is perceived to provide sufficient and justifiable grounds for the development and implementation of disaster risk management policy.

The study concludes that the emphasis on 'evidence-based policy' in earthquake and tsunami risk reduction measures continues, despite the critical reflections of a group of scientists who advocate for a major rethink of the country's science-policy set-up, going beyond the limitations of the current state-of-science.

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IIASA BY PROGRAM

Further information

• Risk management and adaptation

Transitions to New Technologies

The strategic goal of the Transitions to New Technologies (TNT) Program is to further the understanding of the drivers, constraints, impacts, and dynamics of technological change, particularly in the areas that are key for global sustainability. The program also disseminates policy-relevant research findings through high-level global fora and participates in major international cross-cutting research projects and assessments.

Program website   Scientific recognition   Publications   Staff

Selected highlights

Modeling sustainable transport options

Systems solutions for sustainability transitions

In search of viable pathways for sustainable development

Reaching out to the IIASA constituency

Objectives

Technological change arises from the spatial and temporal diffusion of individual innovations all the way up to the emergence of new technological combinations that could fundamentally redefine products, services, and even entire markets. Technological interdependence and interrelatedness, along with knowledge and technology spillovers, and the increasing globalization of research and development (R&D) and technology firms, explains why technological change can no longer be understood or steered from an isolated perspective, or in a piecemeal fashion.

TNT's research strategy consequently focuses on the systemic aspects of technological change and draws on systems theories of innovation, empirical case studies, and novel modeling approaches, as well as scenario studies and robustness analysis, to inform technology policy choices from a systemic perspective. An integrated systems perspective characterizes the policy domains studied by TNT, in particular the Sustainable Development Goals and the nexus (water, energy, land, and air) resource interdependencies that are the subject of two major cross-cutting research initiatives at IIASA. These are The World in 2050 and the Integrated

Solutions for Water, Energy, and Land initiatives that the program helped to co-design and to which it is actively contributing.

Finally, given its comparatively modest size, the TNT Program aims to maximize the visibility and impact of its research through participation in a few key international assessments and major collaborative activities in a joint effort with other IIASA research programs and key international partners. Through its data documentation, dissemination of software, and database tool development, the program also provides a highly valued open data and software service to the international scientific community.

Modeling sustainable transport options

Novel methodological concepts to simulate pervasive policy-driven transformations were for the first time tested in a real-world case study application to analyze policy targets associated with the city of Shanghai's goal of having more electric vehicles on its roads by 2025.

The IIASA Transitions to New Technologies (TNT) Program's pioneering agent-based modeling approaches, which extend the model representation of dynamic technology landscapes by a corresponding representation of networks of interacting producers and users of technologies, reached a new milestone in 2017. Following extensive model development and illustrative test simulations where the new type of model served primarily as a research tool, it was possible for the first time to calibrate the model with empirical data for a case study in the city of Shanghai.

By combining detailed statistics on vehicle registrations and an innovative application-based consumer survey (albeit with a limited sample size), researchers were able to test the agent-based modeling method in terms of how well it could reproduce the historical rapid growth in the vehicle market of the city. In addition to this, the researchers were able to explore policy options for a policy target scenario of one million electric vehicles in the city by 2025. This work is based on a long-standing successful collaboration with researchers from the East China University of Science and Technology (ECUST) in Shanghai.

First results from the study suggest that this highly ambitious target could be feasible if technology innovation push and social/behavioral pull

strategies are combined to change consumer preferences, while maintaining the already highly substantial economic incentives for electric road vehicle purchases.
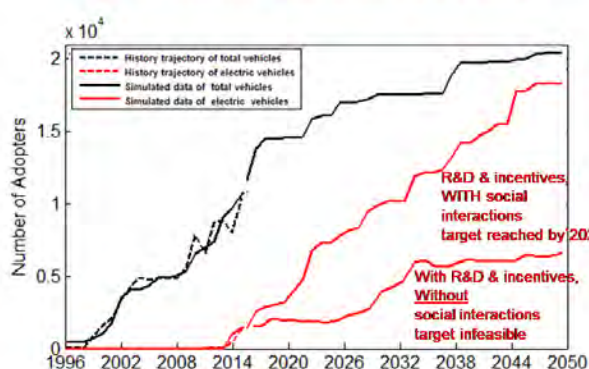
Given this encouraging initial result, a large scale, fully-fledged policy study was initiated. In collaboration with researchers in Israel–who have pioneered novel methods for consumer surveys in new business applications like shared- and electro-mobility–collaborators in China are currently preparing a new, larger scale survey. Research will also continue to extend the agent-based model with an energy systems component that will enable the detailed examination of the resource conservation potential from shared mobility models, as well as the possibility of using a large number of electric vehicle batteries as electricity storage.

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Shanghai Policy Target of >1 Million e-Cars by 2025
Scenarios with R&D and incentives (purchase subsidies and C-tax), and WITH/WITHOUT social network and peer effects

Calibration of historical vehicle market growth in the city of Shanghai with an agent-based model developed by an IIASA-ECUST research team. Also shown are the simulated impacts of technology push policies only, and an integrated approach including demand-pull policies leveraging social network and peer effects. In the latter case, the examined policy target of one million electric cars registered in the city might become feasible by 2028, indicating a case of very rapid transition.

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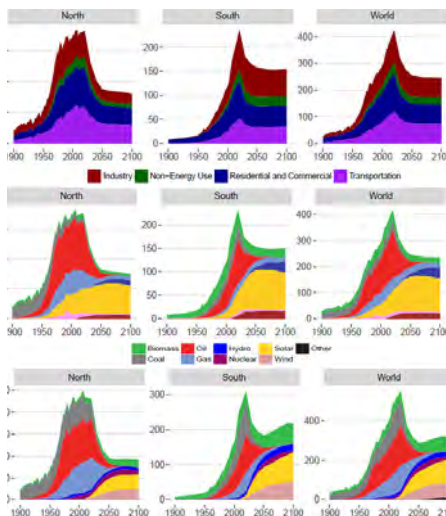
Further information
- TNT models and databases

Systems solutions for sustainability transitions

The Transitions to New Technologies (TNT) Program focuses on the systemic aspects of technological change and draws on empirical case studies, novel modeling approaches, as well as scenario studies and robustness analysis to inform technology policy choices from a systemic perspective.

In 2017, researchers from the program, in collaboration with colleagues from the Air Quality and Greenhouse Gases (AIR), Energy (ENE), and Ecosystems Services and Management (ESM) programs at IIASA, developed a Low Energy Demand (LED) scenario. The research is part of the Alternative Pathways toward Sustainable development and climate stabilization (ALPS) collaborative research project with the Research Institute for Innovative Technologies for the Earth (RITE) in Japan. This scenario is an innovative illustration of alternative pathways for sustainability transitions through an end-use driven approach of technological and behavioral change. A derived scenario variant will also provide the integrative pathway that will be used in the global research initiative–The World in 2050 (TWI2050)–that supports the successful implementation of the Sustainable Development Goals (SDGs).

The LED project was initiated and completed as a fast track research input to the ongoing Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5°C. This project illustrates the comparative advantages offered by small, flexible research programs such as TNT that can act nimbly in response to important research opportunities. The study was also conducted as part of the longer-term ALPS collaboration framework with colleagues from RITE and involved a network of some 20 scientists from the AIR, ENE, ESM, and

End-use and demand-driven "peak energy" in a scenario of meeting a climate target of 1.5°C without negative emissions technologies. Final energy output (EJ, top panels) and primary energy extracted (EJ bottom panels) for the Global North, South and the World respectively. Declining energy needs result from rapid end-use innovations including new technologies, business models, and behaviors that yield step changes in efficiency and reductions in resource requirements, while providing for higher amenities and services in a rapidly developing world.

TNT programs at IIASA, as well as representatives from TNT's network of alumni and research collaborators.

The objective of the study was to develop an illustration of an alternative strategy for meeting the stringent 1.5°C climate target formulated as an aspirational goal at the Paris climate negotiations. Instead of relying on large-scale supply side technological solutions, most notably a massive deployment of so-called negative emissions technologies (removal of CO2 from the atmosphere), the new alternative pathway focuses on end-use, changing forms of service provision like the sharing and circular economy, as well as granular technology options. This could provide a step-change in resource efficiency, leading to a demand-driven "peak energy" that would allow meeting the 1.5°C target without any need for negative emissions technologies and with significant co-benefits for the SDGs.

A specific characteristic of this alternative scenario is that it combines a rich scenario narrative based on the insights gained from TNT's research into historical technology transitions, and potential accelerators for systems changes with detailed modeling studies using IIASA integrated assessment models–GAINS, GLOBIOM, and MESSAGE–to examine the multiple implications of this alternative, rapid transition scenario. A paper is currently in the process of being published in a high-level journal, and the results have already been influential across almost all chapters of the forthcoming IPCC Special Report. A follow-up study extending this new scenario framework for an integrated approach to address SDG12 (responsible consumption and production) is currently being prepared for the TWI2050 initiative.

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In search of viable pathways for sustainable development

The World in 2050 (TWI2050) is a global multi-year, multi-partner research initiative launched by IIASA with international partners that involves almost all research programs at the institute. The main focus of the initiative is on deriving viable pathways for achieving all 17 Sustainable Development Goals (SDGs) and to provide fact-based knowledge to support associated policy processes and implementation issues. The initiative achieved several important research milestones in 2017.

IIASA, together with the Sustainable Development Solutions Network, the Stockholm Resilience Center, and the Earth Institute at Columbia University, launched the TWI2050 initiative in the wake of the United Nations' 2030 Agenda that was agreed in New York in 2015. Using an integrated and systemic approach, TWI2050 aims to address the full spectrum of transformational challenges related to achieving all 17 SDGs. The objective is to provide the science and policy advice needed to achieve these goals in an integrated manner to avoid potential conflicts among the 17 goals and reap the benefits of potential synergies for achieving them together. TWI2050 brings together the leading modeling and analytical teams from around the world, including major policy institutions to analyze possible sustainable development pathways for a systems transformation that achieves the SDGs together, while staying within Planetary Boundaries in the long-term.

Under the leadership of Nebojsa Nakicenovic, IIASA Deputy Director and a researcher with the Transition to New Technologies (TNT) Program who also serves as Executive Director of TWI2050, important progress was made in 2017. The scientific framing of the TWI2050 initiative was completed and a draft paper on defining the SDG target spaces and associated indicators for 2030 and 2050 was completed. Both these papers, along with first drafts of corresponding SDG narratives, were presented and discussed at the third annual TWI2050 meeting, where the working groups also met to deliberate on their work plans around the major themes addressed by the initiative.

These activities are currently being integrated into a first TWI2050 report that will be presented to the UN High Level Political Forum in New York in July 2018. TWI2050 results related to technology policy were also presented to the UN Secretary General's Special Advisory Group on Technology Facilitation where Nakicenovic serves as a member. In addition to the above, the TWI2050 initiative developed a draft funding strategy and was actively involved with the Belmont Forum of Science Funding Agencies to prepare an SDG-related call for research proposals that is anticipated to become a major source of funding for TWI2050-related research globally.

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Further information

- Road maps and instruments for achieving the SDGs

Reaching out to the IIASA constituency

The Transitions to New Technologies (TNT) Program's strategy for engagement with the IIASA science and policy communities include a focus on a few high-level international science and policy initiatives and the dissemination of results from its research activities on various open source web-based platforms. To respond to growing demand for targeted capacity building, the program experimented with a new format in 2017, with three interactive research seminars held in China and India.

Given its small size, the TNT Program relies on a few high-level high-visibility international fora, and science and policy initiatives to disseminate research findings and to engage at the science-policy interface. Key partners at the international level include the United Nations, the World Bank, and in particular the Global Environmental Facility, and the Intergovernmental Panel on Climate Change (IPCC). The World in 2050 (TWI2050) initiative in which the program actively participates, involves more than 30 partners and collaborating institutions. Individual collaborations with researchers involved in ongoing TNT research, involve institutions from multiple countries including Austria, China, Germany, India, Japan, Sweden, UK, and the USA.
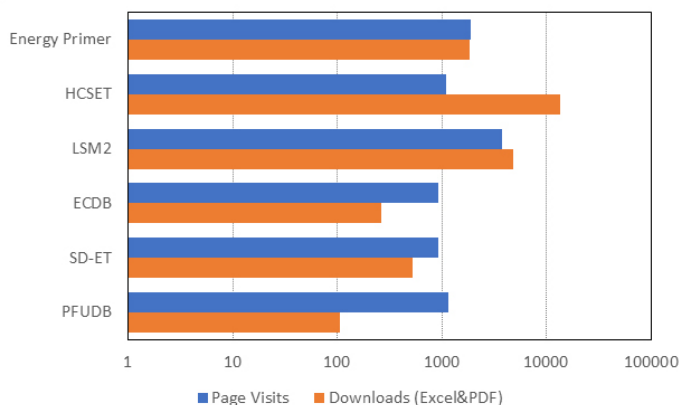
TNT models and databases: Energy Primer; Historical Case Studies of Energy Technologies (HCSET); Logistic Substitution Model 2 (LSM2); Energy and Carbon Emissions Inventories Database (ECDB); Scaling Dynamics of Energy Technologies (SD-ET); Primary, Final and Useful Energy Database (PFUDB).

Documentation of the program's research output is achieved through the IIASA online publication repository PURE, as well as a number of other online resources. The community-service database tools jointly managed by TNT and the IIASA Energy (ENE) Program, and spearheaded by Peter Kolp, have become a hallmark of the institute's mission of supporting scientific research, documentation, and dissemination, and provide the widest possible outreach with limited in-house resources. The use of TNT online tools and the TNT-ENE community service data bases, has grown exceptionally and is fast approaching 100,000 unique visitors and four million page downloads, which represents 54% of all internet downloads for the institute in 2017.
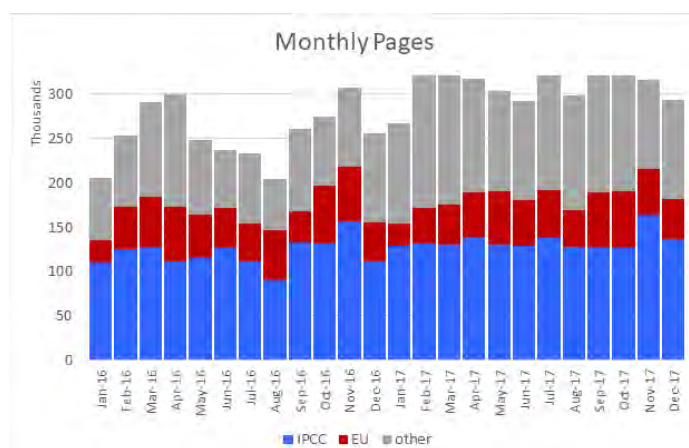
TNT-ENE community service databases and tools: IPCC (AR5, AR5History, RCP, SSP); EU-projects (AMPERE, LIMITS, ADVANCE, CDLINKS); other (all other databases, WorkDb, EMFxx, LAMP, AME, GGI, GEA).

In order to respond to a growing demand for more targeted capacity building outside of the IIASA premises, three interactive research seminars were held at collaborating institutions in China and India in 2017. The events combined a classical seminar format aimed at disseminating conceptual and methodological advances achieved at IIASA with interactive discussion sessions where local researchers presented ongoing research projects for feedback, and explored potential collaboration opportunities. Organized by collaborating or partner institutions in member countries, local seminar participants were selected through a competitive application process. IIASA and the local collaborating or partner institutions jointly developed the overall themes for each event. The workshops held in 2017 comprised a two-day seminar on the topic "Modeling Technological Change" at the East China University of Science and Technology in Shanghai; a five-day seminar titled, "An End-use Perspective on Transitions" at the Centre for Policy Research in New Dehli; and a one-day seminar on the topic "Energy Transformations and SDG Linkages" at the Indian Institute of Technology in Mumbai.

Further information

- TNT Databases
- ENE Databases

Water

The urgent need to address complex and growing water challenges calls for a robust, interdisciplinary approach. The Water Program uses scenarios to explore how different water management policies may affect development in the face of the increasing uncertainty of water challenges. The program provides data, methods, and tools that are consistent across sectors and scales. Together, these drive real improvements in global water security.

(Program website) (Scientific recognition) (Publications) (Staff) (Events)

Selected highlights

Informing sustainable water management options

Asia's looming water crisis

Finding the perfect balance

Exploring sustainable biofuel feedstock potential in Sub-Saharan Africa

Objectives

- Explore new water scenarios and solutions, based on cutting-edge global and regional modeling, seeking breakthroughs not only in understanding problems but also in developing solutions.

- Enhance knowledge sharing through the development of online databases, decision support tools, and online platforms to help communicate and visualize trade-offs and synergies among options.

- Develop an integrated nexus approach combining multi-model analysis across sectors and socioeconomic variables, including governance.

- Provide the analytical backbone for a comprehensive report on global water futures and solutions.

- Foster a multi-stakeholder scientific initiative to define water challenges and identify solution options across sectors at multiple scales by holding stakeholder and donor workshops.

- Establish a knowledge hub for science and policy by developing, maintaining, and harmonizing databases on water-related issues.

Informing sustainable water management options

Water

Pressure on the world's water resources has been mounting substantially in recent decades, and is expected to be further exacerbated by climatic and socioeconomic changes in the future. The Extended Continental-scale Hydro-economic Optimization Model (ECHO) developed by the IIASA Water Program is a useful tool for assessing the economic and environmental impacts of water scarcity and evaluating the effectiveness of management options.

Global water extractions have been increasing rapidly over the last decades to support growing food and energy needs, and increasing standards of living [1]. As a result, many basins around the world have experienced pervasive water scarcity conditions and related water management challenges [2]. These challenges are expected to become even more critical in the coming decades, as countries attempt to sustain a larger and more prosperous human population and economy under changing climatic conditions [3]. As such, policymakers in vulnerable regions need to anticipate how to adapt management practices to secure reliable future water supply that can meet the demands of different sectors. In recent decades, hydro-economic models have emerged as an important tool for informing the design of efficient and sustainable water management options, because they typically feature an integrated biophysical-technological-economic representation of water resource systems [4].

Although hydro-economic models are typically designed at basin scale, with a few designed to model systems ranging in size from household or utility level, to transboundary basin scale, they are rarely used across larger spatial scales. This provides an opportunity to integrate a detailed representation of local biophysical (e.g., available water resources) and technological (e.g., infrastructure) constraints with farther-reaching regional and global policies. This feature is particularly relevant, because the availability of water, energy, and land resources varies significantly at local scales, whereas the linkage to regional and international markets for energy and food commodities, along with transboundary treaties for water resources, have global influences [5]. The few existing large-scale hydro-economic models use a reduced number of spatial units (i.e., location-specific attributes) to minimize the computational burden, which limits their potential for integrating constraints at a local-level. In addition, most of these models only include a limited set of water management options, and many omit the implications of future management decisions in the energy and agricultural sectors.

To overcome these limitations, researchers from the Water Program developed the Extended Continental-scale Hydro-economic Optimization (ECHO) model to support the design of efficient and sustainable water management options. ECHO includes an economic objective function, as well as simplified representations of essential biophysical and technological features at sub-basin level within river basins at a continental scale. These include representations of various water supply sources (surface water, groundwater, and non-conventional water, such as desalinated water), sectoral demands (irrigation, domestic,

manufacturing, and electricity), and infrastructure (surface water reservoirs, desalination plants, wastewater treatment plants, irrigation s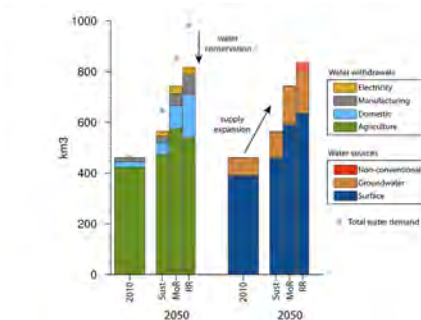ystems, and hydropower plants). The objective function of ECHO minimizes the total costs of a wide variety of water management options over a long-term planning horizon (a decade or more), to satisfy sectoral water demands across the sub-basins. Management options include both supply

Echo model output, showing total water demand, actual sectoral water withdrawals, and water sources in Africa, for various future socioeconomic and climatic scenarios towards 2050.

and demand options that span over the water, energy, and agricultural systems.

ECHO has already been applied to Africa as a case study, in order to assess important interactions between the region's future water demands and availability under various future socioeconomic and climatic scenarios. The model is designed to operate at different spatial scales and in different regions or continents, subject to the availability of data.

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IIASA BY PROGRAM

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Collaborators

- The development of the ECHO model, which involves the IIASA Water and Energy programs, is carried out as part of the larger *Integrated Solutions for Water, Energy, and Land project*.

Further information

- Global Hydro-economic Model
- Integrated Solutions for Water, Energy, and Land (ISWEL)

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Asia's looming water crisis

Climate and socioeconomic change is expected to contribute to water stress in Asia, which means that between 1.6 and 2 billion people could potentially experience severe water stress conditions by 2050. By applying water use scenarios developed by the Water Futures and Solutions Initiative, IIASA researchers for the first time highlighted that socioeconomic change could be the main driver of worsening water security in the region.

Home to almost 4.5 billion people, Asia has experienced unprecedented economic and population growth in recent decades. This has in turn resulted in a substantial increase in water use. Imminent changes due to climate change and socioeconomic development in the region are expected to put even more pressure on water resources in the coming decades. This makes it imperative to evaluate future water scarcity and identify regions at risk in order to inform management strategies, adaptation policies, and planning for sustainable development.

By focusing on Asia as part of a global analysis [1], this study assessed three possible Asian water futures based on a set of consistent and comprehensive climate and socioeconomic projections using three global hydrological models [2]. As part of the modeling process, the researchers extended the latest socioeconomic projections in terms of water, as the original data did not provide enough information for their water use projections. They then combined these extended projections with the latest climate change scenarios using the methodological framework of the IIASA Water Futures and Solutions (WFaS) initiative.

The results highlight that socioeconomic changes have the most significant impacts on water demand growth and overall water stress in hotspots in Asia. While population will peak in some countries before 2050, population and gross domestic product (GDP) are expected to increase in almost all countries across Asia. The resultant growth in, and around mega cities especially, is obvious. Depending on which scenario is applied, industrial and municipal water demands are projected to increase from current levels by between 136-167% or 176-245%.

Climate change is projected to put additional pressure on water resources. In a medium emission scenario, one-third less surface water resources will be available by 2050, when compared to low emissions scenarios. This gap is projected to grow towards the end of the century. Climate change will also result in an increased demand for water in agriculture.

The rapid growth in water demand, in combination with the reduction in available water supply, is expected to increase water stress in Asia considerably, with 20% of the land area subject to severe water stress. The researchers emphasize that a particularly extreme intensification of water stress will occur in the current hotspots of water stress, with an estimated 1.6 to 2 billion people living in the region by 2050. This represents an increase of 38-68% from the 2010s.

Results from a seasonal analysis indicate that most of Asia experiences strong seasonality in water supply and demand, which causes severe water stress over the course of a year, and highlight the need for better planning of water management with season-specific solutions, such as changes in irrigation practices and reservoir operation.

The basin scale hydro-economic analysis also shows that South and East Asian basins have the greatest complexity in terms of the interplay between water availability and climate, with lower coping capacity in South Asian basins. Although coping capacity is expected to improve in all basins, eight basins remain classified in the most vulnerable class (high water complexity combined with low economic strength) by 2050, with large populations living under severe water stress. These regions, in particular, will need effective solutions and better water management to overcome critical water challenges. Increases in coping capacity indicate Asia's potential to achieve this if resources are appropriately allocated.

As a strategic planning method to explore possible futures, this scenario-based approach provides useful insights–particularly in terms of the scale of socioeconomic impacts on water stress. It highlights a clear need for further work on managing water demands and identifying water policy interventions. The analysis, as the first water assessment of Asia in conjunction with socioeconomic projections and climate change scenarios, highlights an urgent need to address water challenges, particularly in the identified hotspots and on the socioeconomic demand side, and underlines the importance of targeted solutions.

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Further information

- Water Futures and Solutions
- Water Futures and Solutions fast-track analysis
- Global Hydro-economic Model

Finding the perfect balance

Water

In many basins across the globe, increasing competition for water resources that serve multiple users in a variety of sectors, along with uncertain climatic conditions, are forcing decision makers to rethink the way in which multipurpose water storage facilities are managed. The IIASA Water Program has developed a novel optimization model aimed at improving reservoir operation in the transboundary Rio Grande basin. This model will enable resource managers to robustly, efficiently, and sustainably, allocate water among multiple users.

As the name implies, multipurpose reservoirs are constructed and equipped to provide storage and release of water for multiple purposes such as flood control, power development, irrigation, recreation, and domestic water supply. The management of these facilities often involve complementary objectives, but also conflicting goals [1]. An objective that has to do with supplying water for use in agriculture for example, would require having the water elevation close to its maximum storage capacity to increase water supply reliability. Conversely, flood management objectives would advocate for an empty reservoir with capacity to manage high, possibly catastrophic, inflows to reduce the risk of overtopping. Integrating water supply for environmental restoration as an additional objective may create even more competition. Different stakeholder groups typically pursue one objective over another, which leads to problems on how to minimize trade-offs among competing water management objectives in the presence of various uncertainties [2].
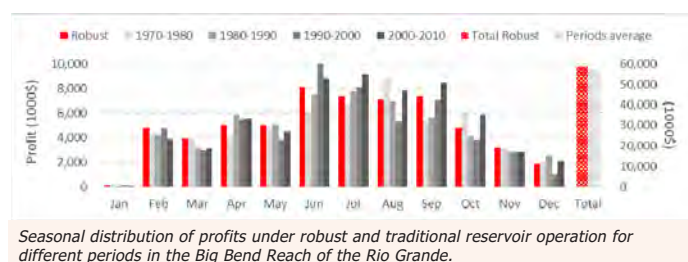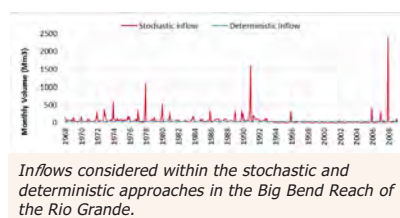
The trade-offs between competing objectives are traditionally managed by reservoir operation rules that dictate the range of water levels in the reservoir at the end of each month. The water level of the reservoir is directly related to its storage capacity, and therefore also to how much water it is able to supply to users. Traditionally, deterministic optimization methods are used to determine the optimal reservoir operation rules. This means that certain variables in real-life systems, such as inflows to the reservoir, water demands, or system losses, become parameters within the model (i.e., average inflow) [3]. Consequently, deterministic optimization models may fail to include the impacts of low probability, but high cost events such as floods or droughts. A major limitation of the deterministic approach is the consideration of a single set of streamflow, that is, the amount of water flowing in a river [4]. In reality, river systems may have high variability over different years, and a deterministic approach is not able to implicitly incorporate extreme floods or droughts in the optimization process.

While working with researchers from the Water Program as a participant of the 2017 IIASA Young Scientists Summer Program, Jose Pablo Ortiz-Partida developed a novel dynamic stochastic optimization model to address this problem [5]. The new model aims to improve reservoir management under uncertain climatic conditions and competition among many water-dependent systems, including water supply for off-stream uses, environmental requirements for healthy ecosystems, downstream delivery commitments, and flood protection. It maximizes regional economic benefits as a function of reservoir deliveries and integrates stochastic inflows into a

water allocation system with different users, and physical and institutional constraints. The model derives robust reservoir operation rules that perform well under a wide range of uncertain climatic conditions.

Inflows considered within the stochastic and deterministic approaches in the Big Bend Reach of the Rio Grande.

The new model was applied to the case of the Big Bend Reach of the Rio Grande–a transboundary river basin of high importance for the United States and Mexico–in order to guide the risk-informed design of efficient and sustainable reservoir operation policies. The results suggest that the operation of the considered reservoir can be enhanced in such a way that higher economic benefits can be achieved in both the United States and Mexico, even while increasing environmental water allocation. The study expands global research on optimizing reservoir operations and has the potential to change current thinking where human and environmental objectives are mutually exclusive.

Seasonal distribution of profits under robust and traditional reservoir operation for different periods in the Big Bend Reach of the Rio Grande.

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Further information
- Transboundary Water Resources

Exploring sustainable biofuel feedstock potential in Sub-Saharan Africa

The Worldwide Fund for Nature South Africa (WWF-SA) has commissioned IIASA to assess pathways towards large-scale, sustainable aviation biofuel deployment in Sub-Saharan Africa, and to address the complex interlinkages in different dimensions of the agriculture-energy-environment system.

The International Civil Aviation Organization has adopted the goal of carbon neutral growth from 2020 onwards (IATA, 2013). Large-scale aviation biofuels, including diverse agricultural feedstocks (i.e., raw materials), are anticipated to play a key role in achieving the target in the longer term.

Biofuels are produced from a range of diverse biomass types, including plant materials, vegetable oils, and starch. As biomass is a limited resource, the aviation sector will add to demand from food, feed, and other non-food agricultural products. To this end, the aviation industry called on the WWF-SA to embed and discuss the development of biomass for energy into a broader perspective of agricultural and socioeconomic development in Sub-Saharan Africa. The region is seen as one of the major expansion areas for the production of biofuel feedstocks.

The guiding principles used for the sustainability assessment were those developed by the Roundtable on Sustainable Biomaterials (RSB), an independent and global multi-stakeholder coalition. The IIASA ecological-economic modeling framework, which comprises the Food and Agriculture Organization of the United Nations (FAO)/IIASA Global Agro-ecological Zones and the IIASA World Food System model, was used to implement the RSB principles on food security, greenhouse gas (GHG) emission saving, environmental conservation, soils, and water management. The researchers defined exclusion layers such as food crops, livestock, safeguard areas of high value for biodiversity and the environment, and quantified them. This revealed some 'unprotected' grass- and shrubland areas that are potentially available for biofuel feedstock production. In addition to current land balances, development scenarios until 2050 evaluated future geospatial patterns of food production and associated land demand.

Once food security and environmental sustainability criteria were accounted for, the balance of remaining land (REMAIN land) was explored for its suitability and capacity to produce a variety of biofuel feedstocks, and assessed in relation to the GHG emissions saving criteria. The assessment included 11 feedstocks ranging from extensively employed, well established conversion pathways (e.g., sugar cane and cereals to bioethanol, or diverse vegetable oil crops to biodiesel) to novel crops (e.g., vegetable oil from solaris tobacco), and second-generation lignocellulosic biomass (i.e., all biomass that has a relatively high content of lignin and cellulose). This has been, and is still being extensively explored in a number of research and demonstration projects (e.g. miscanthus silvergrass).

The results of the study [1] indicate that about one third of REMAIN land, or 1.9 million km2 are agro-ecologically very suitable, or suitable for the production of some annual or perennial biofuel feedstocks. However, exploitation of these land resources will require land conversion from natural shrub- and grasslands to cropland, followed by intensive feedstock cultivation practices. This will in turn result in substantial initial carbon debts due to the removal of the existing vegetation and the partial loss of soil carbon. The sustainability GHG emissions saving criteria set by the RSB requires at minimum a 60% saving relative to the fossil fuel comparator when using a 20-year accounting period. Adhering to this criterion implies that primarily perennial biofuel feedstocks requiring less frequent and less intensive cultivation of soils, can meet the criteria when conversion of natural grassland or shrubland is involved.

The sustainable production potential on prime land quality is restricted to miscanthus (silvergrass), palm oil, and sugarcane, and amounts to a current energy potential of some 6,000 petajoules. Over time, available REMAIN land shrinks because of additional cropland required for food production, which is projected to halve the current sustainable biofuel potential to about 3,000 petajoules by the 2050s. According to the results, annual feedstocks such as sweet sorghum would only be eligible under a less strict GHG criterion that uses a 60% GHG emission saving applied to the biofuel life cycle emissions in each year, and requires a payback period for additional emissions from direct land use change of less than ten years. In such a case, the current potential would increase to 12 thousand petajoules (biofuel equivalent).

In addition to the above, agricultural residues from food production could provide additional biomass for fuel production. When applied to 2010 data, the model shows that allowing 2 tons of crop residues per hectare to remain on the field to comply with the RSB principle on safeguarding soil fertility, results in a useable crop residue potential of 97 million tons (equivalent to 617 petajoules), thus increasing the potential from REMAIN land by 10%. Unlike REMAIN land, which will be decreasing towards the 2050's, cultivated land for food production and associated crop residues will be increasing.

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Collaborators

- World Wildlife Fund (WWF), South Africa
- Roundtable on Sustainable Biomaterials (RSB)

Further information

- Sustainable aviation biofuel supply chains
- Global Agro-ecological Zones (GAEZ)
- World Food System model (WFS)

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World Population

The World Population Program is a global leader in the comprehensive study of the changing number, distribution, and composition of humans on the planet and the effect of these changes on sustainable development. This is essential to complement IIASA work on environmental topics, and makes IIASA the only global change research institute with significant in-house competence on the human population and its wellbeing.

Program website   Scientific recognition   Publications   Staff   Events

Selected highlights

Estimating global migration flows over the past decades

Climate research needs a greater focus on human populations

The state of world population aging

Demography, human capital, and economic growth
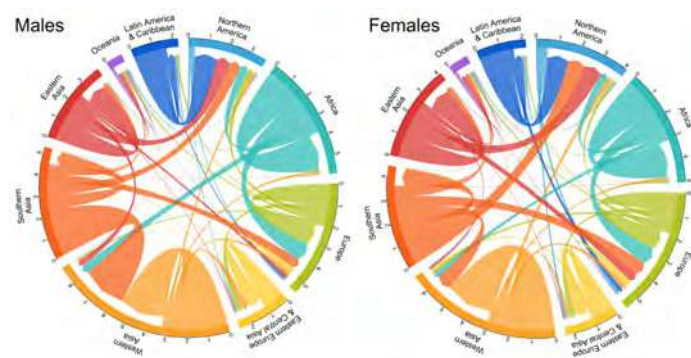
Objectives

- Expand the multi-dimensional model of population dynamics developed at IIASA to include an urban/rural dimension for all countries.
- Define and test alternative specifications of Empowered Life Years, which are the years a person can be expected to be alive and "empowered"— as measured by health, ability to read, freedom from poverty, or subjective life satisfaction.

- Produce the first systematic projections of new indicators of aging, which will explicitly reflect additional dimensions for most European countries and selected other Organisation for Economic Co-operation and Development (OECD) counties. This will go beyond the conventional simplistic indicators which only reflect chronological age.
- Provide policymakers with data pertaining to the likely proportions of urban populations and the

changing age and education structure of urban populations.
- Provide governments and civil society guidance as to what pathways are the most promising for reaching sustainable human wellbeing in the longer term.
- Undertake science-policy dialogues on new measures of aging and the relationship to macro-economic impacts of demographic trends.

Estimating global migration flows over the past decades

World Population

A new indirect estimation methodology, developed and applied by IIASA researchers, has quantified trends in global international migration flows over the past 55 years for the first time. These estimates provide a more comprehensive picture of past migration patterns than currently available figures in reported flow data produced by individual countries, or migrant stock data that do not capture the dynamic nature of movements over time.

Global international migration is an ever-changing process. Migrant stock data commonly used for the analysis of migration patterns, only capture part of the dynamic nature of international migration. An indirect estimation methodology, developed and applied by IIASA researchers, produces bilateral migration flow estimates that are demographically consistent with past population totals, births and deaths, and hence provides a more robust basis for understanding contemporary migration patterns where no comprehensive source of global migration flow data exists [1].

Estimated Migration Flows by Gender during 2010-15.

In their study, the researchers derived estimates of international migration flows by gender, between all countries, for five-year periods between 1960 and 2015. They found that, while estimated global migration flows generally increase over time, the percentage of the global population that migrates remains fairly steady at 0.65 of the global population over each five year period. This result supports similar findings in the migration literature on the lack of empirical evidence for the acceleration in global international migration, and suggests a shift in the directions of flows linked to major geopolitical and economic movements.

The bilateral estimates produced in this study quantify trends in global international migration flows over the past 55 years for the first time. Traditional migration receiving countries such as Australia, Canada, New Zealand, and the USA, for example, have seen continuously increasing numbers of migrants arriving. More recent growth is evident into countries in Northern-, Southern-, and Western Europe, while a growing number of migration flows were estimated along migrant corridors between countries in South Asia (such as Bangladesh, India, and Pakistan) to West Asia (such as Qatar, Saudi Arabia, and the United Arab Emirates), and from Asia to North America. In addition, large migrant transitions were also estimated in selected periods within Africa or Eastern Europe during times of armed conflict or political change.

The estimates produced can potentially be used as inputs into global population projection models. International projection-making agencies commonly use simplistic assumptions of net-migration measures derived as residuals from demographic accounting. However, past net migration can often be volatile and introduce bias when projecting populations [2]. The bilateral migration estimates produced in this research however, allow for more detailed scenarios to be formulated based on changes in migration patterns related to changing future push and pull factors in origin and destination countries, and corridor specific factors related to linkages between countries or groups of countries.

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Collaborators

- Asian Demographic Research Institute (ADRI), China

Further information

- New institute for Asian demographic research
- IIASA-JRC Centre of Expertise on Population and Migration

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Climate research needs a greater focus on human populations

The way in which climate change will affect future populations will depend largely on people's capacity to adapt to changing conditions. According to IIASA researchers, such characteristics can be forecast in the long term using well-established demographic methods.

Climate research has provided a range of scenarios showing how climate change will affect global temperatures, water resources, agriculture, and many other areas. Yet it remains unclear how all these potential changes could affect future human wellbeing. In particular, the population of the future – in its composition, distribution, and characteristics – will not be the same as the population observed today. That means that assessing likely impacts by relating the climate change projected for the future to today's societal capabilities can be misleading. In order to understand the impacts of climate change on human beings, climate change research needs to explicitly consider forecasting human populations' capacities to adapt to a changing climate.

The demographic tools to do this are already available and well established. Global IIASA population and human capital scenarios up to the year 2100 include not just numbers of people, but also their distribution by age, sex, and education level. These scenarios form the human core of the Shared Socioeconomic Pathways (SSPs) that are widely used in research related to climate change.

In an article based on a growing body of research from IIASA and the Vienna Institute of Demography [1], which was published in the journal Nature Climate Change [2], IIASA researchers discuss a conceptual model that can account for the changing characteristics of populations through the replacement of generations, called "demographic metabolism."

Podcast: The focus on human populations in climate change research. Interview with IIASA researcher Raya Muttarak

The concept of demographic metabolism can be described as the process whereby individuals in a population are constantly replaced, just like cells turn over in a body. People of today differ in many ways from their parents and grandparents, and the same will hold true for future generations. They differ in education levels, in health, environmental awareness, and many other factors—and what the research has shown is that these factors directly affect a population's vulnerability to natural disasters or changes in the environment.

The researchers explain that some characteristics that people acquire early in life, like education, remain with them throughout their lives.

Research by the IIASA World Population Program has shown that education in particular influences how vulnerable people are to natural disasters like floods and storms, which are expected to increase as a result of climate change. With more educated younger generations replacing the older ones through the demographic metabolism process, it may be possible to anticipate a future society with higher adaptive capacity.

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IIASA BY PROGRAM

Further information

- Forecasting Adaptive Capacity to Climate Change

- Climate research needs greater focus on human populations

- Education – Preparation for the unexpected

The state of world population aging

The rapid increase in both the number and proportion of older persons in the five BRICS countries (Brazil, Russia, India, China, and South Africa) will have multifaceted implications for social and economic development. The first BRICS Meeting on Aging organized by the United Nations Population Fund (UNFPA) China provided a comprehensive review of developments in the field of population aging in these countries.

In 2015, BRICS countries were home to over 380 million older persons aged 60 and above. This represents about 42% of the world's population and the trend is projected to move upwards. Such a rapid increase in both the number and proportion of older persons will have multifaceted implications for the social and economic development of these countries, as well as for their social and economic transition in the coming decades.

The first BRICS Meeting on Aging organized by the United Nations Population Fund (UNFPA) China, provided a comprehensive review of developments in the field of population aging in BRICS countries. In particular, discussions during the event focused on common challenges faced by these countries, analyses of national experiences in coping with, and harnessing opportunities presented by aging, and the presentation of findings and recommendations for BRICS countries and others.

Policymakers, academics, students, and private sector representatives from BRICS countries, attended the event. Invited participants from other countries also took part in the discussions to provide wider and in-depth input on meeting topics.

As an established expert on aging in Russia and beyond, World Population Program Deputy Director Sergei Scherbov was invited to attend the meeting and brainstorm with other participants on how to promote collaborations on aging among BRICS countries. He gave a presentation on the state of world population aging as measured using the newest indicators developed at IIASA.

Scherbov, together with Warren Sanderson, has been developing new measures of age and aging in demographic research for many years. They suggest broadening research methods to account for significant increases in life expectancy, as the focus on chronological age of people alone provides a limited picture of the process–one that is often not appropriate for either scientific study or policy analysis. Their groundbreaking results have been published in Nature and Science, as well as in other high-level journals. Scherbov is principal investigator of the Reassessing Aging from a Population Perspective (Re-Aging) project at IIASA that, among other things, ascertains the extent to which advanced societies are actually aging in multiple dimensions, including health, cognitive abilities, and longevity.

The 2017 meeting on aging included three components: a) Responses of BRICS countries to population aging; b) Data on aging in BRICS countries; and c) Innovative practices on aging in BRICS countries.

The meeting was jointly hosted by the China National Committee on Aging (CNCA), Renmin University of China (RUC), and the United Nations Population Fund (UNFPA) in China, and organized by the China Research Centre on Ageing (CRCA), and the Institute of Gerontology at RUC.

The 1st BRICS Meeting on Aging took place in Beijing, China from 6 to 7 December 2017.

https://youtu.be/Bq9_uj9xghk

Further information

- Reassessing Aging from a Population Perspective (Re-Aging) project
- The state of world population ageing

Demography, human capital, and economic growth

The Asian MetaCentre, IIASA, and the Wittgenstein Center (IIASA, VID/ÖAW, WU) organized two workshops at the Asian Demographic Research Institute (ADRI), Shanghai University, attracting participants from more than 20 countries from around the world.

A workshop on modeling and projecting sub-national population trends was held from 7 to 11 April 2017. The event focused on the analysis of recent trends in subnational (provincial) populations stratified by age, sex, education, and urban/rural place of residence. It also looked at developing alternative scenarios for the future following the Shared Socioeconomic Pathways (SSP) narratives and Sustainable Development Goal (SDG) scenarios.

economic growth around Asia. Participants engaged in discussions about the so-called first and second demographic dividends and on the role of human capital as a determinant of economic development. Leading international experts from IIASA, Vienna Institute of Demography (VID), and ADRI gave lectures providing overviews of the state of knowledge in these fields.

Image © ADRI, Shanghai University.

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More than 25 participants, primarily from Asia, developed country/region specific population models for Bangladesh, China, Hong Kong, India, Indonesia, Iran, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand. During the workshop, demographic and data issues in each country were discussed, followed by an introduction to the methodology of multistate demography. A hands-on training session with an R-package (MSDem, Multistate Demography) was also conducted. The results are expected to be of high policy relevance for national and sub-national planning in the countries concerned.

The first Asian summer school on demography, human capital, and economic growth, took place from 19 to 23 June 2017. The school hosted more than 15 PhD students and postdocs from around the world and focused on how demographic trends and improving educational attainment impact

Collaborators

- Asian Demographic Research institute (ADRI), China
- Wittgenstein Centre for Demography and Global Human Capital, Austria

Further information

- Modelling and projecting sub-national population trends workshop
- Demography, human capital, and economic growth summer school

Futures initiatives

The IIASA futures initiatives are cross-sectoral projects designed to explore plausible futures for a number of the world's rapidly changing regions and resources. Current futures initiatives cover a number of issues affecting the Arctic, tropical regions, economic integration in Eurasia, and water management around the world.

Arctic Futures Initative

Selected highlight:

The future of Arctic populations

Eurasian Economic Integration

Selected highlight:

Looking ahead: Future opportunities in the greater Eurasian space

Tropical Futures Initiative

Selected highlight:

Safeguarding the future of the tropics

Water Futures and Solutions Initiative

Selected highlight:

Solutions for a water secure East Africa in 2050

PROJECTS & INITIATIVES

The future of Arctic populations

Only 10 million people live in the vast 20 million square kilometer territory surrounding the North Pole. This relatively small number of local people, are however one of the driving forces in active Arctic transformation. The IIASA Arctic Futures Initiative explored what the Arctic population might look like in the future by applying an innovative projection methodology that factors in level of education.
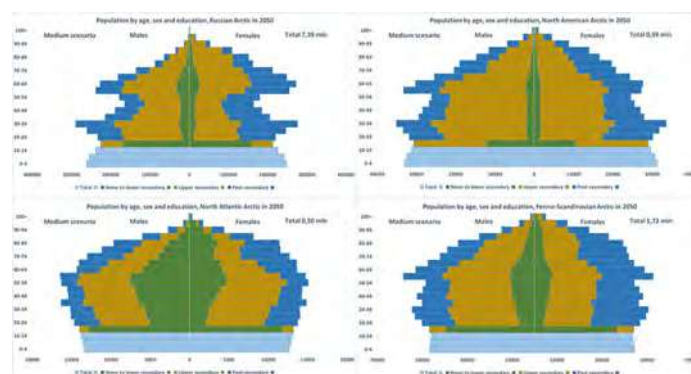

Coverage of the Arctic area

The Arctic region covers more than 10% of the planet's total land area, but is one of the most desolate and least populated areas on earth because of its isolated location and harsh climate. Due to rapid and extensive changes in the region, people and places in the north are facing challenges to their livelihoods, environment, and culture. Climate change, industrial extraction, pollution, globalization, migration, and food- and water insecurity, along with widening socioeconomic gaps in the region, are not only affecting Arctic residents, but also have global consequences. Understanding the population dynamics and human capital associated with these changes will be crucial to finding solutions and addressing problems in the future.

In 2017, an IIASA study examined recent population developments in the Arctic and modeled future demographic trends towards 2050 [1]. To account for regional characteristics, the researcher incorporated assumptions on the processes of population change that are explicitly Arctic in nature in addition to global patterns. The age and sex parameters of interest, as well as the level of higher education based on the fertility and mortality of people with different education levels, were also explored.

This was done by applying three alternative scenarios for the future, which the researcher termed "medium development", "arctic boost", and "arctic dip" respectively. The medium development scenario projects a continuation of Arctic trends in the recent past, while the other two consider migration as a larger cause of demographic change. The arctic boost scenario implies a multi-faceted boom in the region based on an increase in the number of migrants, changes in climatic conditions, and technological developments. It also implicates faster education progression between educational levels, as well as an increase in the number of people with the highest qualifications who contribute to the boost. The arctic dip scenario in turn, entails accelerating out-migration as a driver of future population decline, combined with a number of larger constraints to development in the Arctic. In this scenario, the progression of population groups to higher levels of education is much slower or even halted for the highest educational levels, as many qualified students/professionals may decide to pursue further education and careers elsewhere.

Total population of the Arctic by its four major constituting regions, 2050, Medium scenario

The resultant population projections suggest how education as a factor of human capital may drive demographic shifts in northern parts of Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the US. The innovative approach of projecting the population by level of education has not previously been applied to studies on the Arctic. Several communities have already expressed interest in the results, which could provide value input for stakeholders on decisions concerning the future development of this highly vulnerable and complex region.

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Further information

- Peace Symposium
- International Congress on Arctic Social Sciences

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Looking ahead: Future opportunities in the greater Eurasian space

Towards the end of 2017, young researchers, senior experts, and high-level policymakers had the opportunity to engage in vibrant discussions on possible futures for the greater Eurasian space in 2040, and the potential of youth to contribute to economic cooperation and sustainable economic development in the region.

As part of the IIASA Futures Initiative "Challenges and Opportunities of Economic Integration within a wider European and Eurasian Space", IIASA hosted the International Youth Forum: Future of Eurasian and European Integration: Foresight 2040, from 4 to 8 December 2017.

The event was co-organized by IIASA and the Institute for Economic Strategies of the Russian Academy of Sciences, with financial support from the Russian Gorchakov Public Diplomacy Fund.

A total of 40 talented young minds, together with senior experts and high-level policymakers from the European Union, the Eurasian Economic Union, the Commonwealth of Independent States, and East-, and South-East Asia, engaged in a vibrant brainstorming session on possible futures for the greater Eurasian space in 2040. Discussions included issues pertaining to economic-, humanitarian-, and security dimensions. The young participants evaluated the impact that currently emerging trends such as demographic changes, digitalization of the economy, block chains, and 3D-printing are going to have on regional economic integration. A foresight report based on these deliberations will be published in 2018. As a highlight of the forum, the young participants buried a time capsule containing an appeal to the youth of 2040 to be opened in that year.

During the final day of the forum the young researchers took part in the high-level event, "Connectivity, trade, and economic cooperation in the European and Eurasian space", organized by IIASA on the margins of the 24th Organization for Security and Co-operation in Europe (OSCE) Ministerial Council at the Hofburg Palace in Vienna.

Recognizing the potential of youth to contribute to economic cooperation and sustainable economic development, OSCE invited a representative of the Forum to speak to the Council's guests. Marina Steiniger, a junior economist at the Ifo Institute for Economic Research Center for International Economics, was selected to report on how young people perceive future opportunities for closer economic cooperation in the wider European and Eurasian space.

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Funders

- Eurasian Economic Commission
- Eurasian Development Bank

Further information

- Eurasian Economic Integration
- Future of Eurasian and European Integration: Foresight–2040
- High-level session at OSCE Ministerial Council
- Joint workshop on economic integration between Europe and Eurasia
- High-level consultation on Eurasian economic integration

Collaborators

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- Ifo Institute for Economic Research, Center for International Economics

Safeguarding the future of the tropics

Futures initiatives

The tropics are home to the greatest biodiversity on the planet and provide vital climate regulation. The Tropical Futures Initiative (TFI) brings together scientists from various disciplines and institutions to help governments and key decision makers implement sustainable pathways for these important regions. In 2017, TFI succeeded in becoming the first IIASA Futures Initiative to secure significant external funding under the RESTORE+ project.

The overarching objective of the Restoration for Land Use Sustainability in the Tropics (RESTORE+) project is to provide decision makers in the tropical region with lasting capacity, technical recommendations, and enhanced datasets to inform the restoration of degraded and marginal areas at the Food-Land-Energy nexus. This calls for an approach that links qualitative information with socioeconomic and environmental parameters to obtain a comprehensive assessment of degradation and restoration. Beyond bridging science to policy, RESTORE+ also aims to develop a generic methodology that can be applied to other regions. To this end, while focusing on detailed assessment activities in Indonesia and Brazil, the project also covers the Congo Basin, to conduct dissemination and research outreach activities.

In Indonesia, the project specifically aims to inform key national and sub-national policies such as the country's medium-term economic development plan (or RPJMN as it is commonly referred to in Indonesia), nationally determined contribution (NDC), climate resilience strategy, and national biodiversity strategies and action plan (NBSAP).

Other than quantifyable results, this requires the project to also deliver modeling tools that can be used for further analyses or related inquiries in the broader land use context. RESTORE+ aims to deliver an Indonesia specific modeling toolbox comprising detailed modeling results of the Environmental Policy Integrated Model (EPIC), the Global Forest Model (G4M), the Techno-economic Spatial Optimization Model (BeWhere), enhanced remote sensing products utilizing the citizen-sourced Geo-Wiki approach, and the Global Biosphere Management Model (GLOBIOM). The project will also allow groundtruthing for the usefulness and policy impact of IIASA's exploratory work.

In 2017 for example, the IIASA Wildfire Climate Impacts and Adaptation Model (FLAM), was applied to the Tropics for the first time, with a study devoted to the application of this model to Indonesia. FLAM captures the complex impact of climate, population, and fuel availability on burned areas, using a process-based fire parameterization algorithm that was originally developed to link a fire model with dynamic global vegetation models. The version of the model applied in Indonesia however, features new modeling approaches compared to the original model applied to Europe. As model development and assessment requires joint capacity building and close collaboration with local stakeholders, enhanced capacity in modeling and the analyses of results are also crucial outcomes of the RESTORE+ project.

In Brazil, RESTORE+ benefits from the successful results of the preceding International Climate Initiative (IKI)-funded REDD Policy Assessment Centre (REDD-PAC) project. Other than generating important technical assessments that forms the basis of Brazil's NDC, REDD-PAC also resulted in the Global Biosphere Management Model (GLOBIOM) for Brazil [1], and other local modeling capacities that will further contribute to the RESTORE+ project. At this stage, the goal of the project is to inform, among others, ministry regulations, and technical- and policy guidelines that contribute to the implementation or enhancement of Brazil's Forest Code to help achieve objectives such as those in its NDC and NBSAP.

In the Congo Basin, project activities focuses on ensuring that stakeholders in the region (e.g., Ministries of Forests and Environment, the Commission of Central African Forests (COMIFAC), CN-REDD offices, and Ministries of Agriculture) endorse the project in terms of its potential contribution to policy formulation and relevant stakeholder activities. Selected training activities will also be undertaken throughout the project to enhance capacity in the region.

A consortium of 10 institutions led by IIASA collaborate on the RESTORE+ project. The project forms part of the IKI and is supported by the German Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety (BMUB).

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Collaborators

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- Instituto de Pesquisa Econômica Aplicada (IPEA), Brazil
- UN Environment World Conservation Monitoring Centre (UNEP-WCMC)
- Mercator Institute on Global Commons and Climate Change (MCC), Germany
- Environmental Defence Fund (EDF), USA

- Grantham Research Institute on Climate Change and the Environment (LSE), UK
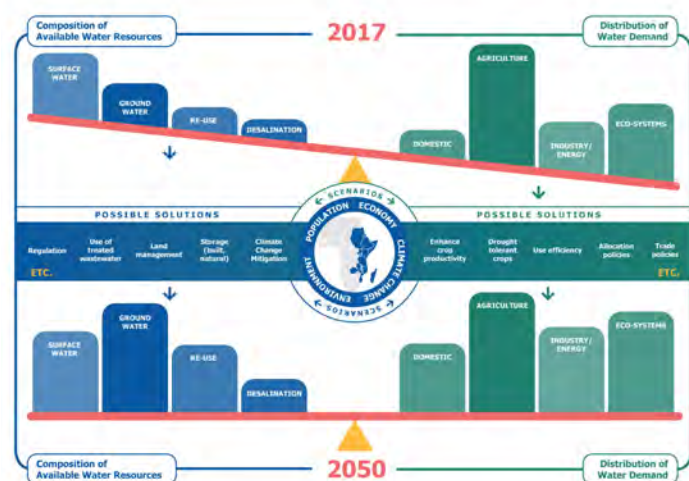- Landmapp, Ghana

Further information

- RESTORE+
- FLAM

Solutions for a water secure East Africa in 2050

The IIASA Water Futures and Solutions Initiative seeks to incorporate science into water policy and planning, and applied water management issues. Set up as an interdisciplinary scientific initiative, the project identifies and tests solution pathways across different economic sectors, including agriculture, energy, and industry, while safeguarding the environment.

The Water Futures and Solutions Initiative engages with stakeholders from across the globe to support and codesign future development scenarios and possible options for the management of water resources. It provides important input that support mid- to long-term water management and planning based on informed decision making. After a global analysis undertaken in a first fast-track assessment, the initiative is now focusing on Eastern Africa with the Lake Victoria basin as a key research area. With funding from the Austrian Development Agency, the Water Futures and Solutions Initiative formed an East Africa node. This corresponds with one of the priority regions of Austria's development cooperation policy.

Key actors of the Lake Victoria basin like the Lake Victoria Basin Commission and its member countries, the Nile Basin Initiative, and the Global Water Partnership, among others, expressed interest to engage in mutual learning and participate in model development and the co-creation of scenarios of future water demand and regional water management options. Regional stakeholders worked with a team of four IIASA staff members to identify priorities, development pathways, and potential for investments and solutions. In light of the above, Uganda in collaboration with IIASA, co-hosted a three-day workshop in Entebbe, Uganda, on the issue of projecting future water demand and water availability in the Lake Victoria basin.

The workshop, which took place in December 2017, attracted more than 50 practitioners engaged in government, academia, business, and civil society in the East African community, to discuss mid- to long-term water resource management options towards 2050. For many of the participants, the workshop presented a first opportunity to discuss systems thinking approaches aimed at understanding future development scenarios and their implications for water management practices.

Each workshop day had a particular focus with highly interactive and engaging discussions triggered by participatory facilitation techniques. The discussions on the opening day revealed a number of key challenges and opportunities concerning the use of modeling to support informed water resource planning decisions. One full day was dedicated to gaining a deeper understanding of development scenarios resulting from the East African community's vision for 2050. Discussions focused on how water can support development aspirations as an enabler, and how water resources are likely to be adversely affected as a result thereof. The final day of the workshop saw participants building partnerships on boosting modeling and scenario building capacities in the region. This will likely form the basis of future research collaborations and work packages, which will either be implemented in the coming year, or developed into funding proposals.

To this effect, a joint funding proposal involving interested partners from East African academic institutions, which was collaboratively developed between the Lake Victoria Basin Commission, Uganda and IIASA, will be elaborated and submitted to a range of development partners already engaged in transboundary water management issues in the region. This could be of significant interest to a range of other IIASA member countries apart from Austria, who have similar priorities and interests.

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Further information

- Solutions for a Water Secure East Africa
- WFaS: Fast-Track Analysis
- Water Futures and Solutions Initative

Large-scale initiatives

IIASA has multiple large-scale initiatives supporting major transformations in our changing world. These innovative and interdisciplinary projects span a wealth of topics ranging from how to attain the UN Sustainable Development Goals, to solutions for jointly meeting water, energy, and land demands at the global level. The overarching goal of these initiatives is to provide fact-based knowledge that will ultimately contribute to achieving true sustainability on a global scale.

Integrated Solutions for Water, Energy, and Land (ISWEL)

Selected highlight:

Identifying development and climate vulnerability hotspots

The World in 2050 (TWI2050)

Selected highlight:

In search of viable pathways for sustainable development

Identifying development and climate vulnerability hotspots

Large-scale initiatives

Understanding the interplay between multiple climate change risks and socioeconomic development is increasingly required to inform policies to manage these risks in pursuit of the sustainable development agenda. To this end, IIASA researchers working on the Integrated Solutions for Water, Energy, and Land (ISWEL) project conducted a comprehensive assessment of the potential exposure of global and vulnerable populations to multi-sectoral climate risk hotspots under different levels of global warming.

The 21st century will see the global population increase from 7.5 billion in 2017, to an expected 8.5-10 billion in 2050 [1]. Future populations will be exposed to a growing range of climate change hazards of varying intensities, with some areas–or hotspots–exposed to more risks than others [2]. These risks are not just dependent on the severity of climate change and subsequent hazards, but also hinges critically on the population's exposure, and their vulnerability and capacity to prepare for and manage changing risks. Recently, a few studies have brought attention to the fact that the world's poorest are disproportionately exposed to climate risks, such as changes in temperature extremes and challenging hydro-climatic complexity [3].

In order to inform effective, integrated policy responses to these problems, it is necessary to assess the exposure of future global and vulnerable populations to multi-sector climate impact hotspots. IIASA researchers working on the ISWEL project investigated where the main multi-sector risk hotspots are located globally, how they might change with higher levels of global mean temperature rise, and to what extent socioeconomic development and poverty reduction can reduce risks. The results of their assessments indicate that, although global exposure to multi-sector risks will affect a relatively small fraction of global land area, the risks to human populations will be large.

The general structure of the assessment comprised the development of 14 climate and development indicators across the water, energy, and land sectors, and the aggregation of impacts and risks using new and established methods to produce multi-sector risk hotspot maps. These maps were then compared for 1.5°C, 2.0°C, and 3.0°C changes in global mean temperature above pre-industrial conditions. The exposure of global and vulnerable populations (i.e., those with an income of less than US$10 per day) was also investigated using three socioeconomic projections from the Shared Socioeconomic Pathways (SSPs 1-3). The results of these assessments are presented at the global grid and Intergovernmental Panel on Climate Change (IPCC) region scales.

Looking to understand the differences between the temperature targets in the Paris Agreement, the researchers found that the differences between 1.5 and 2.0°C were considerably larger than expected. The increase in exposed population to multi-sector risks almost doubles from 1.5 to 2.0°C, and similarly doubles again at 3.0°C (from 1.5 to 2.7 to 4.6 billion). Both the scale of and the differences between these numbers underline the benefits of climate mitigation that will be experienced across the world, predominantly in developing regions.

For populations vulnerable to poverty, the importance of targeted poverty eradication to reduce vulnerability is clear. The differences between the SSP1 (sustainability–affluent, low inequality, high education) and the SSP3 (rocky road–development failures, high inequality, low education) socioeconomic pathways, potentially alters the number of exposed and vulnerable population by an order of magnitude. In all scenarios, the exposed and vulnerable population lie disproportionately in Asian and African regions (91-98%), with approximately half living in South Asia alone. As the most undeveloped region, Africa faces worse risks than most regions, especially in high inequality socioeconomic scenarios and high warming climate scenarios.

Climate mitigation alone will not be enough to reduce the exposure of the world's poorest, who will still be vulnerable to impacts at 1.5°C. According to the researchers, action to rapidly reduce inequality, eradicate poverty, and promote proactive adaptation through mechanisms such as the Sustainable Development Goals, would greatly reduce the size of exposed and vulnerable populations, especially if co-benefits for climate mitigation also accrue.

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Funders

- Global Environment Facility (GEF)
- United Nations Industrial Development Organization (UNIDO)

Further information

- Integrated Solutions for Water, Energy, and Land (ISWEL)

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In search of viable pathways for sustainable development

The World in 2050 (TWI2050) is a global multi-year, multi-partner research initiative launched by IIASA with international partners that involves almost all research programs at the institute. The main focus of the initiative is on deriving viable pathways for achieving all 17 Sustainable Development Goals (SDGs) and to provide fact-based knowledge to support associated policy processes and implementation issues. The initiative achieved several important research milestones in 2017.

IIASA, together with the Sustainable Development Solutions Network, the Stockholm Resilience Center, and the Earth Institute at Columbia University, launched the TWI2050 initiative in the wake of the United Nations' 2030 Agenda that was agreed in New York in 2015. Using an integrated and systemic approach, TWI2050 aims to address the full spectrum of transformational challenges related to achieving all 17 SDGs. The objective is to provide the science and policy advice needed to achieve these goals in an integrated manner to avoid potential conflicts among the 17 goals and reap the benefits of potential synergies for achieving them together. TWI2050 brings together the leading modeling and analytical teams from around the world, including major policy institutions to analyze possible sustainable development pathways for a systems transformation that achieves the SDGs together, while staying within Planetary Boundaries in the long-term.

Under the leadership of Nebojsa Nakicenovic, IIASA Deputy Director and a researcher with the Transition to New Technologies (TNT) Program who also serves as Executive Director of TWI2050, important progress was made in 2017. The scientific framing of the TWI2050 initiative was completed and a draft paper on defining the SDG target spaces and associated indicators for 2030 and 2050 was completed. Both these papers, along with first drafts of corresponding SDG narratives, were presented and discussed at the third annual TWI2050 meeting, where the working groups also met to deliberate on their work plans around the major themes addressed by the initiative.

These activities are currently being integrated into a first TWI2050 report that will be presented to the UN High Level Political Forum in New York in July 2018. TWI2050 results related to technology policy were also presented to the UN Secretary General's Special Advisory Group on Technology Facilitation where Nakicenovic serves as a member. In addition to the above, the TWI2050 initiative developed a draft funding strategy and was actively involved with the Belmont Forum of Science Funding Agencies to prepare an SDG-related call for research proposals that is anticipated to become a major source of funding for TWI2050-related research globally.

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Further information
- Road maps and instruments for achieving the SDGs

Cross-cutting projects

Cross-cutting research at IIASA draws on expertise from across the institute's research programs. These primarily methodology-focused projects represent unique and unaddressed research challenges that require integrated and interdisciplinary expertise and focus.

Equitable governance of common goods

Selected highlight:

Alleviating the tragedy of the commons

Dynamic vegetation models: The next generation

Selected highlight:

Laying the foundation for a new generation of models

Socioeconomic heterogeneity in model applications

Selected highlight:

Consumers, development, and the future of wellbeing

Systemic risk and network dynamics

Selected highlight:

Improving the resilience of systems

PROJECTS & INITIATIVES

Alleviating the tragedy of the commons

Cross-cutting projects

Measures for protecting common goods – such as mitigating climate change or not overexploiting natural resources – are collectively beneficial, yet costly to the individual stakeholders that must invest in them. Common goods may thus be jeopardized by selfish agents, resulting in social dilemmas that often follow a pattern known as the 'tragedy of the commons'.

The tragedy, however, is not inevitable. There are abundant cases of common goods, even with weak regulatory regimes, that are thriving. In 2017, the Equitable Governance of Common Goods (EGCG) project focused on unpacking the complexities that characterize common-good governance based on predictions from game theory, plural rationality, and bounded rationality. This was accomplished through case studies, experimental games, experiential games, and agent-based and stylized models.

EGCG case studies provide evidence for the hypothesis that understanding and resolving the governance challenges associated with common goods require accounting for a plurality of values and preferences among stakeholders. In particular, it necessitates accounting for the four socially determined worldviews suggested by the theory of plural rationality: empirical studies have suggested that worldviews observed across a wide array of thematic domains and social contexts tend to cluster into individualistic, hierarchical, egalitarian, and fatalistic perspectives.

Among many case studies, the EGCG case on forest management in Nepal was one of the project's highlights in 2017. In 1979, the World Bank predicted that by 2000, 'no accessible forests will remain in Nepal' [1]. Today, however, Nepalese forests are flourishing. This success story is attributed to Nepal's community-based approach to forest conservation, which balances commercial timber interests with community control and entitlement conferred on forest user groups, all subject to stringent government regulation [2]. The Nepalese case study is embedded in a larger effort to rethink development aid in Nepal [3]. The rationale behind this new approach is that constructive and argumentative engagement of stakeholders with their plural rationalities is crucial for the governance of common goods.

With a focus on forest governance, the EGCG project has also devised three experimental games that explore the key predictions on common-good governance from game theory, plural rationality, and bounded rationality.

In 2017, the project highlighted the results from the first of these Forest Games [4]. The game demonstrates differential correlations between the average forest condition resulting from a group's harvesting and its average rationality or worldview, as revealed through a questionnaire developed by the researchers. The findings indicate that egalitarian worldviews improve a group's ability to preserve a forest (positive correlation), whereas individualistic and hierarchical worldviews have the opposite effect (negative correlations).

In the absence of options for real-world hands-on learning, 'serious role-playing games' can effectively provide simulated real-world experiences.

For this purpose, the EGCG project has developed several experiential games related to common-good governance.

The Water-Food-Energy Nexus Game, for example, which was jointly developed by the EGCG project and the IIASA Water Program, is an integrated simulation game that addresses the interrelated challenges of water, food, and energy production [5]. This game not only underscores the social dilemma involved in governing water as a common good, but also shows the added complexity of interrelated (nexus) issues with food and energy production.

In addition to the above, EGCG research strives to elucidate how the four worldviews recognized by the theory of plural rationality interact and how governance regimes – emerging bottom-up or imposed top-down – promote the successful management of common goods.

Another 2017 project highlight was the development and analysis of a first game-theoretical model of social dynamics under plural rationality. The researchers studied governance agendas whose alignments with individualistic, hierarchical, and egalitarian worldviews can change dynamically based on stakeholder influences. While the model is relatively simple, its dynamics are surprisingly rich, exhibiting several phenomena predicted by theory, such as the endogenous self-organized emergence of plural rationalities and cyclic social dynamics. The model results show how insufficiently inclusive governance agendas are constantly being undermined, leading to perpetual social change through which different worldviews become intermittently dominant.

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Collaborators

- Evolution and Ecology Program, IIASA
- Risk and Resilience Program, IIASA
- Water Program, IIASA
- Faculty for Mathematics, University of Vienna, Austria
- Institute for Science, Innovation, and Society, University of Oxford, UK
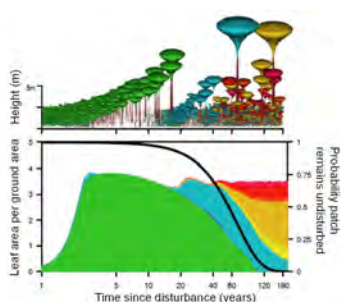- Centre for Systems Solutions, Wroclaw, Poland

Further information

- Equitable Governance of Common Goods

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Laying the foundation for a new generation of models

Dynamic global vegetation models (DGVMs) were first conceived at IIASA twenty-five years ago and have since become indispensable for understanding the biosphere and estimating ecosystem services. However, while their versatility is increasing as new processes and variables continue to be added, their accuracy suffers from the accumulation of uncertainty, especially in the absence of overarching principles controlling their concerted behavior.

The crosscutting IIASA project Dynamic vegetation models: The next generation (DVM) aims to address this problem by developing the foundations of a new generation of models centered on a 'missing law' – adaptation and optimization principles rooted in natural selection. Even though this missing law constrains relationships between traits, and can therefore vastly reduce the number of uncertain parameters in ecosystem models [1], it has rarely been applied to DGVMs. The project is working towards operationalizing this concept through scientific discussion and research collaboration in an international working group of leading experts from multiple disciplines coordinated by IIASA.
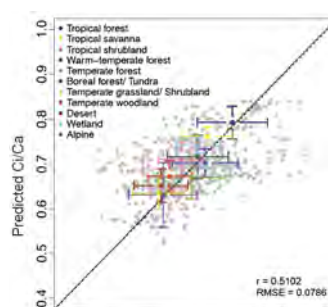

A model of trait evolution and species coexistence recovers natural vegetation patterns from around the globe.

The project utilizes the convening power of IIASA to attract a wide range of members of the international scientific community of vegetation modelers to discuss and evaluate state of the art models, current limitations, and promising ways forward. Building on results of a recent DVM workshop, two papers are being prepared. The first of these is a review laying down a roadmap for the next generation of vegetation models, while the second is a perspective paper assessing the power of overarching organizing principles, including those of adaptation and optimization, for improving vegetation models.

Several studies have been conducted to explore these new concepts. These include an optimization-based photosynthesis model published in Nature Plants [1], a new model for adaptive tree growth [2], a study of the global effects of leaf optimization [3], an adaptation-based model of forest trait diversity published in PNAS [4], and a comment on mycorrhizal effects on global CO2 fertilization published in Science [5].

The findings of the above studies demonstrate the potential of adaptation and optimization principles for modeling plant and forest dynamics. In one of the studies, for example, researchers developed a model of trait evolution and species coexistence that recovers natural vegetation patterns from around the globe [4]. In this model, plant species inhabit a metacommunity of patches and differ in two functional traits, namely leaf mass per area and height at maturation. After a disturbance, vegetation development in a patch follows successional dynamics under height-structured competition

A universal model of photosynthesis reduces parameter uncertainty in vegetation models.

for light. The upper panel of Figure 1 shows the height of individual plants in a diverse community of species (colors) in a patch in the wake of a disturbance. The lower panel in turn, shows the corresponding prevalence of species (left vertical axis and colored areas) as the probability that a patch remains undisturbed decreases (right vertical axis and black line) for an average interval between disturbances of 60 years.

Using uniform parameters in conjunction with a least-cost optimality hypothesis, another model developed by researchers from the project predicts photosynthesis and associated leaf-internal-to-ambient CO2 partial pressures for multiple biomes (Figure 2). This model is driven by temperature, vapor pressure deficit, and elevation. The figure compares model predictions with observations from the global delta 13C dataset, with means and standard deviations indicated for each biome (colored lines). The model explains the observed variation among biomes, as shown by the resultant regression line (continuous black line constrained to pass through the origin), which is very similar to the 1:1 line (dashed black line) [1].

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PROJECTS & INITIATIVES

| IIASA Contributors | • Advanced Systems Analysis
• Ecosystems Services and Management
• Evolution and Ecology | Further information | • Dynamic vegetation models: The next generation
• First workshop of the working group |

Consumers, development, and the future of wellbeing

Cross-cutting projects

As society recognizes and endeavors to combat threats to the environment, it is becoming increasingly clear that heterogeneity in human consumption behavior should receive greater attention to understand the impacts created by human development. The cross-cutting Socioeconomic Heterogeneity in Model Applications (SCHEMA) project focused on how accounting for socioeconomic heterogeneity in integrated assessments can improve both the prediction of global environmental change and their impacts on human wellbeing.

The project, which was completed in 2017, was a collective effort between four IIASA programs: Energy, Ecosystems Services and Management, Air Quality and Greenhouse Gases, and World Population. The aim was to generate a common layer of socioeconomic inputs that feed into at least three global models namely, the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), the Global Biosphere Management Model (GLOBIOM), and the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model. These inputs enabled the generation of more detailed representations of household diversity, specifically in aspects of basic subsistence, including food demand, cooking fuels, and related exposure to air pollution. The geographic focus of the project was India–a developing country with high socioeconomic contrasts.
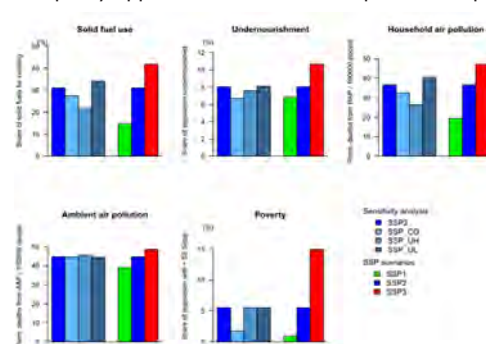
The SCHEMA project has led to significant methodological advances and substantive insights in the different IIASA domains addressed by the cross-cutting team. Existing IIASA models were modified to incorporate primary drivers of change into the projections and future scenarios of food demand and undernutrition, cooking fuels, and related health impacts from exposure to harmful substances emitted by these fuels (wellbeing dimensions) [1].

Detailed projections of future demographics and income inequality were generated for different states, taking into account urbanization rates and intra-national migration patterns. Income inequality projections accounted for increasing technology-driven skill bias and education improvements. These primary drivers were then converted into food and energy demand projections at national and state level. The results revealed that socio-heterogeneity significantly affects the results of the projections.

According to the researchers, understanding food and energy demand in the country is difficult without looking at patterns across socioeconomic groups. Average national GDP per capita masks poverty levels due to the unequal distribution of income within the country, and fails to account for the different levels of uptake of clean cooking fuels in urban and rural India. Furthermore, the relative contributions of higher and lower income groups to ambient air pollution vary significantly for different activities, for instance cooking in contrast to transport and other economic activities. In the case of

food consumption, the researchers performed a detailed analysis of Indian consumer expenditure over a period of twenty years (1993-2012), which allowed them to identify the most important drivers of change in dietary patterns over this period. Income distribution, urbanization, and aging were identified as key factors to understand the future of food demand and nutrition in the country. The Figure reveals the new capabilities of the IIASA models to project basic wellbeing dimensions under different socioeconomic futures.

In short, the project has laid a foundation from which multiple research and policy applications can be developed. The representation of different

SCHEMA wellbeing indicators (related to basic subsistence) for India in 2040 under different scenarios showing percentage of population (higher is less wellbeing). Shared Socioeconomic Pathways (SSP): SCHEMA-customized SSPs. SSP1: equitable world; SSP2: middle of the road; SSP3: unequal world. Three sensitivities SSP_UH/SSP2_UL: SSP2 with high/low urbanization. SSP_CG: SSP2 with constant Gini (low inequality).

household groups enables the assessment of distributive impacts of various policies and policy shocks in all relevant sectors, such as carbon pricing, agricultural policies, or pollution control measures. Some of these policies can propagate through energy and food prices, where they have impacts on air pollution, greenhouse gas emissions, and other dimensions of wellbeing. This kind of analysis can potentially help identify winners and losers by, for example, identifying groups that bear undue pollution exposure without proportionate contributions to emissions. Additional scenarios can also be devised to assess particular objectives, such as the Sustainable Development Goals (SDGs) and other national development objectives.

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Further information

- Socioeconomic Heterogeneity in Model Applications
- GAINS
- MESSAGE
- GLOBIOM

Improving the resilience of systems

Systemic risk describes the likelihood of cascading failures in networks. Such risks arise in a broad range of different systems, such as power grids, ecosystems, supply chains, financial networks, disease dynamics, and transportation networks. The Systemic Risk and Network Dynamics (SRND) cross-cutting project at IIASA, aims to develop capabilities for analyzing systemic risks and to demonstrate how to assess and mitigate risks of cascading failures.

While most existing approaches to systemic-risk assessment are application-specific, similarities between systems offer great potential for cross-fertilization and synergetic analyses. Specifically, the project is developing cross-cutting measures of systemic risk, prognostic tools for assessing the likelihood and extent of cascading collapses under uncertainty, methods for reducing systemic risk through network design and control, and new approaches to the governance of systemic risk.

The project explores systemic risk in a broad range of applications from natural to human-made systems. In 2017 for example, researchers working on the SRND project explored the effectiveness of credit default swaps (CDSs) as an alternative or complementary instrument to the systemic risk tax studied earlier [1]. Over recent years, CDSs have acquired a negative reputation, as they are widely used for speculations, which are seen as exacerbating financial systemic risk. However, using an economic-financial model, the results of one study [2] showed that, by properly shifting financial exposures from one institution to another, a CDS market can be designed to rewire the network of interbank exposures in ways that make it more resilient to insolvency cascades.

The project also developed and used an agent-based model (ABM) simulating a national economy previously developed by its researchers, to estimate the indirect economic consequences of direct losses arising from floods. This model is the first to use a 1:1 scale to represent a country's natural persons and legal entities, such as firms and banks, and to simulate their interactions. The ABM is currently calibrated for Austria, using data from national accounts, census data, and business information. It is driven by a probabilistic flood model, which uses the copula approach to predict flood losses while accounting for spatial dependencies. In this way, the researchers link environmental and economic processes in a nationwide simulation. Their analysis predicts that moderate floods induce positive indirect economic effects in the short and medium term, and small but negative indirect economic effects in the long term. In contrast, large-scale floods result in a more pronounced negative economic response in the long term. This approach allows the researchers to identify winners and losers in unprecedented detail across all economic sectors, as well as fiscal consequences for the government, both of which are crucial for managing extreme events resulting from climate change and natural disasters. A paper presenting these findings has been submitted for publication.

Furthermore, the project's work on systemic risks in ecosystems is ongoing. Researchers working in this thematic area analyze how species losses propagate through food webs. In particular, they have developed what has become the world's largest database of quantified food webs, and have used this information on ecosystems from around the globe to calibrate their models. This provides a unique basis for addressing controversies that have persisted in the ecological community for decades, concerning the question of which structural features make food webs more or less vulnerable to species loss. The researchers have expanded this resilience analysis from the ecosystem level to the species level.

Since its inception, the SRND project has been enabling the three participating IIASA programs to pool their methodological expertise on dynamic systems, risk analysis, and network theory. In light of this, a perspective paper is being prepared that presents an integrated approach using the copula methodology, for combining individual risks (in the form of probabilistic distributions) and systemic risks (in the form of copulas describing the dependencies among such distributions). This approach is especially useful when extreme events (occurring at low probabilities, but having high impacts) that affect agents in a system can lead to a tightening of the connections between some or all agents, as is often the case in, for example, financial systemic risks.

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PROJECTS & INITIATIVES

IIASA Contributors

- Advanced Systems Analysis Program, IIASA
- Evolution and Ecology Program, IIASA
- Risk and Resilience Program, IIASA
- Complexity Science Hub, Vienna, Austria
- Department of Statistics and Operations Research, University of Vienna, Austria

Further information

- Systemic Risk and Network Dynamics

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Our people

IIASA sees its people as its most valuable asset and continues to attract and retain world-class talent. Researchers from member countries working at the institute gain access to all aspects of the IIASA network and can contribute to building the systems analysis capacity of their home countries. More than 300 international researchers from around 50 countries currently work for IIASA, while another 3,500 researchers, science-to-policy workers, and diplomats from about 65 countries are actively involved in the institute's activities.
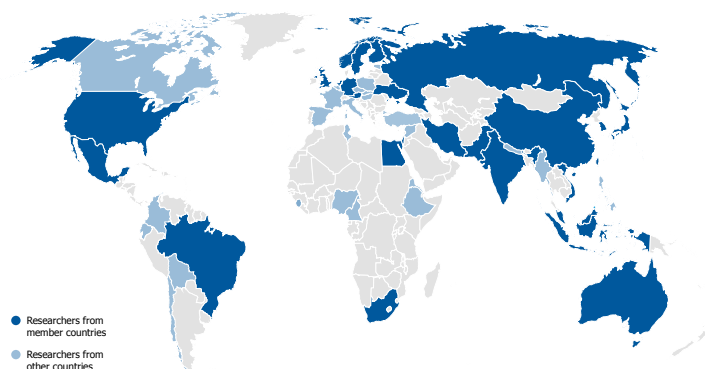
People management

Following a period of rapid expansion in the number of researchers and staff working at the institute, IIASA has placed a high priority on human capital management for the next five years. In 2017, a new staff performance evaluation system was introduced, and a new diversity policy is currently being developed.
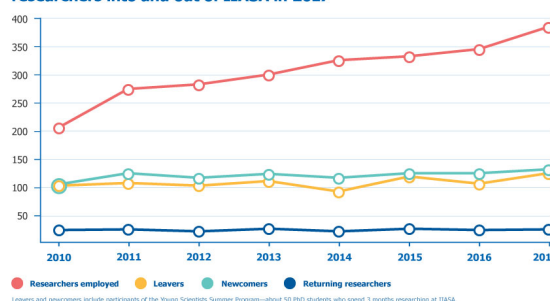
In addition to Austrian labor law, a series of federal laws concerning IIASA and international organizations in Austria provide the institute and its employees with a range of immunities and privileges. This allows IIASA to offer competitively advantageous employment conditions compared to Austrian employers (Austrian federal law and official gazettes: BGBl. Nr. 117/1973; BGBl. Nr. 677/1977; BGBl. Nr. 344/1978; BGBl. Nr. 476/1978; BGBl. Nr. 441/1979; BGBl. Nr. 219/1981; BGBl. Nr. 609/1990; BGBl. Nr. 666/1994).

Human resource policies and procedures are in place for staff categories, personnel procedures, overtime, leave, maternity regulations, childcare benefits, retirement, temporary assignment, incentive payments, good scientific practice, conflicts of interest and commitment, code of conduct, outside interests, housing services, and health and safety rules. These policies are contained in the IIASA handbook and staff rules and regulations (sections 4.2 and 4.3 of the IIASA Operating Procedures and Policies). The appointment of new staff and extension of existing staff contracts is managed and documented through the forms and approval processes of the IIASA management information system.

Number of researchers employed and the flow of existing researchers into and out of IIASA in 2017

Researchers employed • Leavers • Newcomers • Returning researchers
Leavers and newcomers include participants of the Young Scientists Summer Program—about 50 PhD students who spend 3 months researching at IIASA.
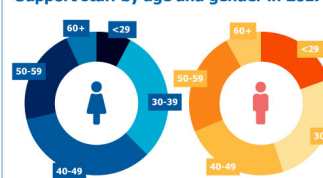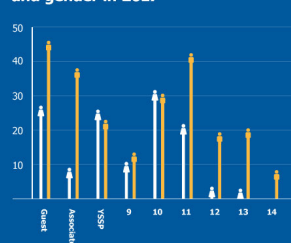
144 Part time researchers

238 Full time researchers

Researchers by age and gender in 2017
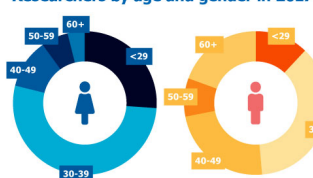
Support staff by age and gender in 2017

Researchers by level of employment and gender in 2017

Support staff by level of employment and gender in 2017

Female • Male

Category 9 is junior scientific staff with a bachelor's degree or above, working as scientific support. Categories 10-16 are experienced research staff (postdocs, research scholars, program directors, the deputy director general, and the director general), with an advanced university degree (minimum at level 10 is a Master's degree). Young Scientists Summer Program (YSSP) participants, associates, and guest research scholars are listed separately.
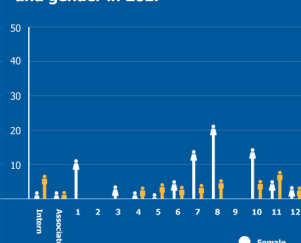
Categories 1-8 are general service staff in procedural or operational roles. Categories 10-14 are professional staff with analytical, evaluative, and conceptual roles, with a degree or relevant work experience. Interns and associates are listed separately.

In 2017, 382 researchers from 48 different countries worked at IIASA

● Researchers from member countries
● Researchers from other countries

IIASA guidelines and regulation for good scientific practice

The IIASA guidelines and regulations for good scientific practice were updated in 2016. They are intended to contribute to the prevention of scientific misconduct, conflicts of interest and commitment, while promoting quality science. The institute recognizes its responsibility to nurture an environment of mutual respect, tolerance, and ethical behavior according to the general principles outlined in these rules. No cases of scientific misconduct arose in 2017.

OUR PEOPLE

Diversity and equality

Many of the characteristics that make IIASA unique also present challenges for both the attractiveness of the institute as a place to work and for the retention of high-quality employees. The international nature of IIASA, while being a distinct advantage, also raises challenges in terms of managing cultural, social, and geographic diversity.

The institute was founded with a commitment to the principles of equal opportunity, anti-discrimination, gender balance, cultural accommodation, and geographical distribution in its hiring, promotion, and administrative practices. With a staff comprising over 50 nationalities, it is an inherently diverse institution.

In the past years, IIASA initiated a multi-faceted examination of diversity in all its aspects. The process included taskforces that collected and analyzed employment data at IIASA, conducted surveys and interviews, delved into diversity literature, and prepared reports, as well as diversity-focused discussions at meetings and retreats. The purpose of this exercise was the definition and institution of a set of policies and administrative practices that both set and achieve targets for increased diversity throughout the workforce, and foster a workplace environment that accommodates diversity in all its forms.

A Diversity Taskforce produced a draft Diversity Policy, which included both statements of principles and aims, and called for the development of diversity goals, timelines, and strategies. In 2017, the Council issued Resolution 696 in support of ongoing and planned actions. This includes the formation of a holistic diversity strategy that will be developed by IIASA with the assistance of an external consultant. The initial terms of reference would be an assessment of diversity, an analysis and benchmark of diversity compared with other organizations, and the development of a vision for a more diverse workforce. The Human Resources department will report back to Council on the ongoing progress and planned actions by November 2018.

To underline the importance of offering equal opportunities, IIASA explicitly states its commitment to a working environment that promotes equality, diversity, tolerance, and inclusion within its workforce in all job advertisements, and encourages

qualified candidates of both genders and from all religious, ethnic, and social backgrounds to apply.

In 2017, IIASA staff continued to benefit from the services of the Institute Counselor, a Human Resource Consultant and Cognitive Behavior Therapist, for confidential support with the challenges and opportunities related to living and working in an international scientific environment. In her capacity as work psychologist, she also provides coaching and counseling related to cultural and social diversity and work environment issues. The Institute Counselor provides twice-yearly anonymized updates and statistics to management to address any issues that may arise.

Detailed figures regarding gender balance by age and by level of employment for scientific and administrative staff are shown in the infographic.
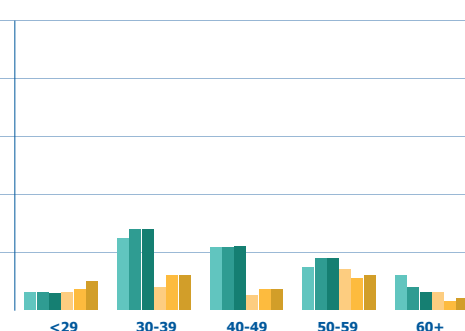
Age, gender, and employment at IIASA

● Female 2015 ● Female 2016 ● Female 2017 ● Male 2015 ● Male 2016 ● Male 2017
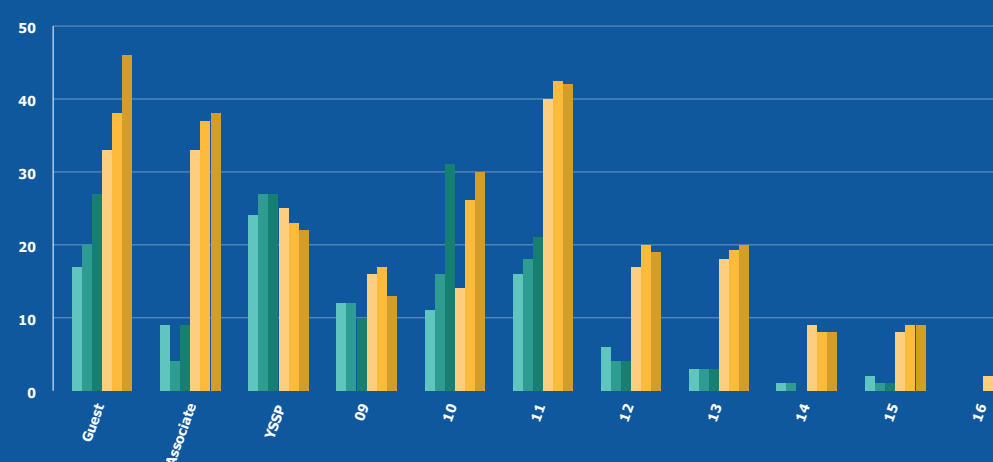
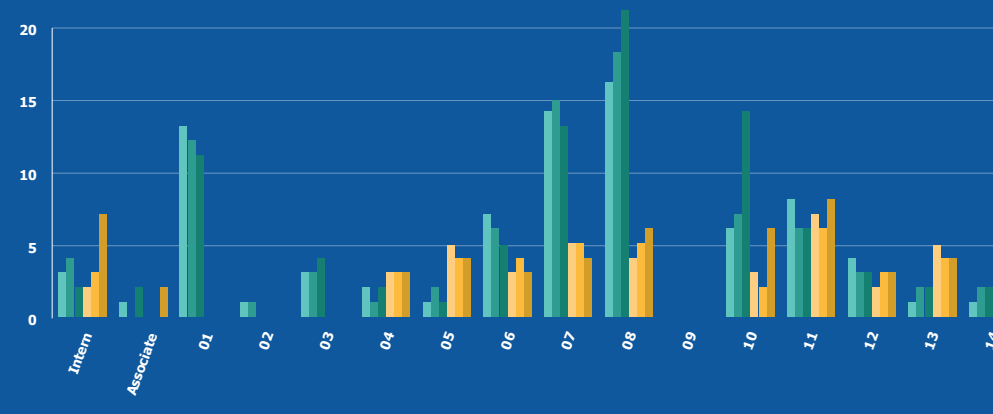### Researchers by age and gender
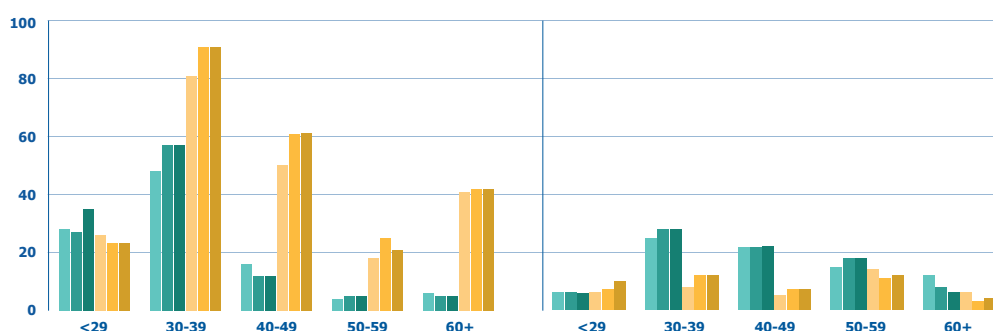
Support staff by age and gender

Researchers by level of employment and gender

Support staff by level of employment and gender

OUR PEOPLE

Capacity development and training

In 2017 the Capacity Development and Training (CDAT) team issued new guidelines for Young Scientists Summer Program (YSSP) supervisors to clarify the responsibilities and necessary qualifications for prospective candidates. The guidelines specify that the supervisor has to ensure that the YSSP candidate's proposal is feasible, guide the research, and if appropriate and consensual, support and guide the participant if he or she wishes to broaden the research, or make it more interdisciplinary. **The qualifications for supervision eligibility were defined as:**

- Sufficient knowledge of a candidate's topic and methodology
- A PhD or equivalent
- Planned absence from IIASA during the YSSP, including vacations and business travel limited to about three weeks.

The supervisory tasks were summarized as:

- Making contact with the participant before the summer program commences in June
- Meeting regularly with the participant
- Establishing milestones/deadlines for research progress with the participant
- Checking mid-summer progress
- Ensuring the scientific quality of the work
- Assisting with the participant's presentation for the end-summer workshop
- Encouraging the participant to meet the report-submission deadline
- Nominating the participant for a Peccei or Michaelevich award
- Engaging more broadly in the YSSP
- Flagging issues that may be detrimental to a participant's summer experience to the YSSP team

In 2017, the CDAT team also proposed guidelines for postdoctoral engagements at IIASA, including information regarding hosting and mentorship, the core research agenda, non-IIASA activities, program-specific activities, and regular reviews and advice. These guidelines are in the final stages before implementation and will become part of the postdoctoral information provided to prospective postdoc candidates.

IIASA Code of Conduct

All IIASA staff must be treated equally and with respect, regardless of gender, race, religion or belief, nationality, ethnic or social origin, age, sexual orientation, marital status, or other aspects of personal status. No behavior that constitutes harassment, sexual harassment, discrimination, bullying, retaliation, or any related acts is tolerated.

The IIASA Code of Conduct Policy for a Professional Working Environment was updated in 2016. This policy specifically extends personnel procedures to include unprofessional behaviors in the workplace, namely: harassment, sexual harassment, discrimination, bullying, and retaliation.

The responsibilities of the institute, staff, and management are clearly outlined in the Code of Conduct. IIASA staff found to be in breach of these conditions are subject to disciplinary action in accordance with Article IX, Disciplinary Measures of the IIASA Staff Rules and Regulations. This may include an oral or written reprimand, or summary dismissal in accordance with the applicable Austrian laws. The failure by management to address a violation of the Code of Conduct that has come to their attention may result in appropriate legal or disciplinary measures being taken against them.

No official complaints of misconduct were reported to the IIASA Human Resource Department in 2017.

IIASA Performance Appraisal Policy

In 2017, IIASA updated its Performance Appraisal Policy and initiated the first appraisal cycle under the new process. This policy establishes the framework for the annual performance appraisal of each employee against established expectations and in accordance with the mission and goals of their scientific program or department, as well as those of the IIASA Strategic- and Research Plans, and their associated documentation. The new policy aims to foster transparency and trust by setting clear guidelines for both supervisors and employees: **The prerequisites of a constructive appraisal are:**

- Mutual feedback between partners of equal worth
- Trust and orientation towards development
- Open dialogue and mutual respect

The performance appraisal:

- Promotes cooperation between the supervisor and the employee
- Identifies training/counseling needs when discussing shortfalls in performance and future development
- Motivates the employee and agrees future objectives and performance standards

The policy was distributed along with the guidelines setting out tasks and explaining the process, as well as new appraisal forms.

Network and collaborators

Our people

Network and alumni

In 2017, 382 researchers from 48 countries worked at IIASA. With its global research network of over 3,500 scholars comprising collaborators, alumni, and visitors from different countries and disciplines, the institute provides science based insights into critical issues with global significance.

4,028
alumni from 94 countries, among them leaders in academia, government, and the private sector

91
advisory boards and steering committees incorporating IIASA researchers

170
externally funded projects where IIASA was lead or partner

396
journal articles in collaboration with over 1,600 coauthors from 159 institutions in 65 countries
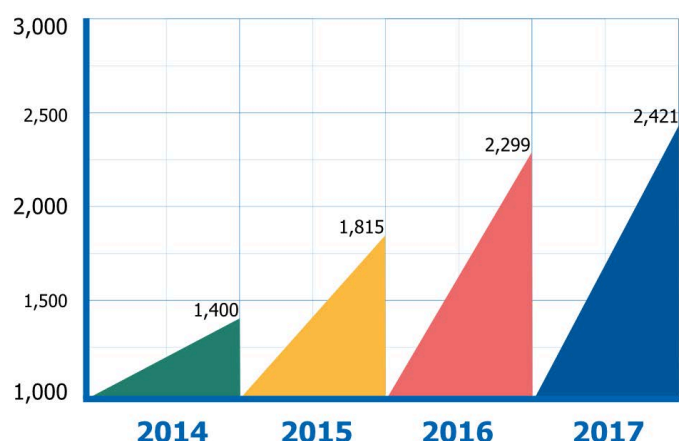
IIASA Network

- **Research network** IIASA has a worldwide network of 3,500 scholars who contribute to research by collecting, processing, and evaluating local and regional data that are integrated into IIASA models. The institute has over 830 research partner institutions in member countries, and works with research funders, academic institutions, policymakers, and individual researchers in national member organizations.

- **Visitors** In 2017, 2,421 associates and scholars visited IIASA to do research, collaborate with the institute's research programs, and to attend IIASA-organized events. Of these visitors, 1,831 were from member countries.

- **Meetings and events** In 2017, IIASA scientists hosted or coordinated 98 events worldwide. Of these, 77 were convened in Laxenburg. The events were attended by a total of 1,942 participants, of which 1,448 were from member countries.

- **Alumni Association** IIASA has 4,028 alumni from 94 countries, 25% of whom are actively involved in the institute's scientific activities. Many alumni are leaders in academia, government, and the private sector. The Alumni Association aims to connect former staff with current IIASA colleagues, thus providing numerous channels to support the institute and its work.

- **Distinguished Visiting Fellows** The institute welcomes visits by eminent scholars from around the globe. Sir Peter Gluckman became a Distinguished Visiting Fellow in 2017.

- **Alpbach–Laxenburg Group** Founded by IIASA and the European Forum Alpbach, the group continued its strategic partnership in 2017, bringing together some of the world's best minds from government, academia, business, civil society, and the arts. These science-based, policy-centered deliberations focused on how to enact transformative change towards enhanced sustainability and equity.

Visitors and conference participants >

Strategic partnerships and collaborations

In 2017 IIASA launched a strategic partnership with the Organization for Economic Co-operation and Development (OECD). The partnership aims to combine the world-renowned scientific expertise of IIASA with OECD's powerful analytical capacities and unique political access and influence. This will not only facilitate the development of innovative models and methodologies to tackle systemic risks and harness cross-cutting opportunities, but also bring these concepts closer to real-life implementation in view of reaching the UN Sustainable Development Goals. At the same time, the partnership will promote systemic thinking across the OECD to cope with today's pressing demands.

In addition, IIASA signed strategic Memoranda of Understanding with the International Food Policy Research Institute and the Royal Scientific Society of Jordan, as well as a number of agreements on specific research collaborations with, among others, the Russian Foundation for Basic Research and the US National Renewable Energy Laboratory. Furthermore, an innovative partnership was launched with the food manufacturer Ferrero, who will fund research looking into the sustainability of palm oil.
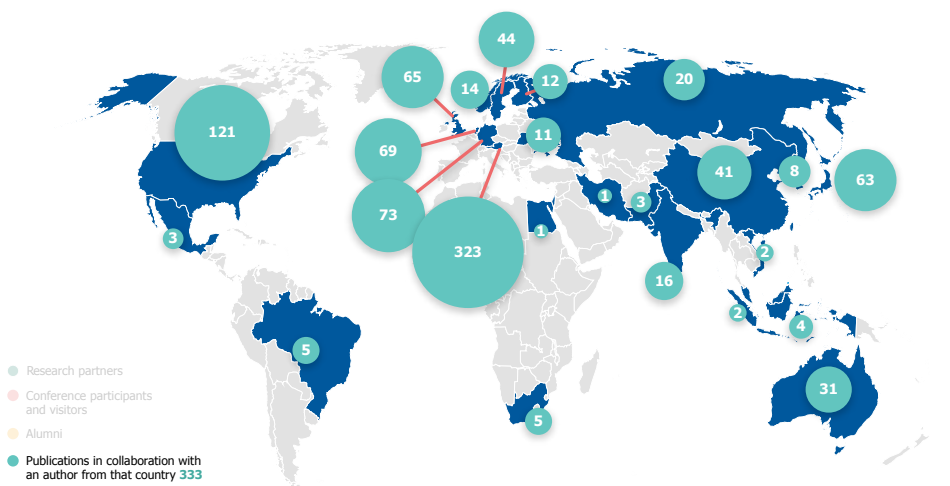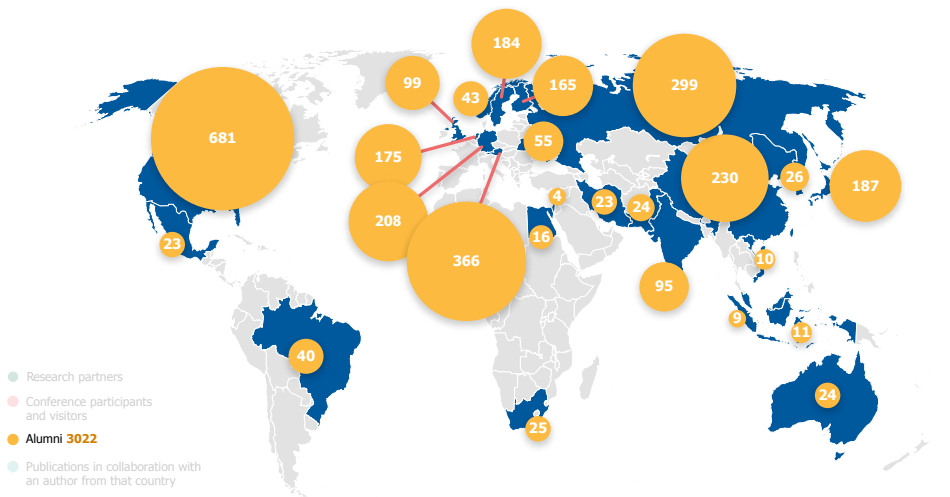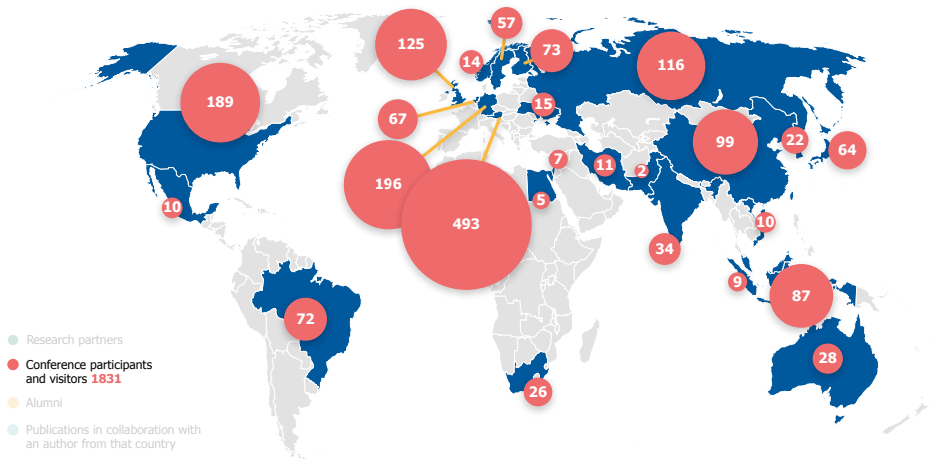
During 2017 IIASA also provided scientific support to the Austrian Chairmanship of the Organization for Security and Co-operation in Europe.

	2014	2015	2016	2017
	1,400	1,815	2,299	2,421

Research partners 833
- Research partners 833
- Conference participants and visitors
- Alumni
- Publications in collaboration with an author from that country

Conference participants and visitors 1831
- Research partners
- Conference participants and visitors 1831
- Alumni
- Publications in collaboration with an author from that country

Alumni 3022
- Research partners
- Conference participants and visitors
- Alumni 3022
- Publications in collaboration with an author from that country

Publications in collaboration with an author from that country 333
- Research partners
- Conference participants and visitors
- Alumni
- Publications in collaboration with an author from that country 333

NETWORK & COLLABORATORS

Governance

IIASA is governed by a Council comprised of one permanent representative from each National Member Organization. Regulations concerning the institute's objectives, conditions of membership, internal structure, and the roles and responsibilities of the Council are outlined in the institutional Charter.

National Member Organizations

Each IIASA member country designates a National Member Organization (NMO) to represent the nation's scholarly community, and act as a bridge between their research and policy communities and the institute. There are three types of NMOs namely, national academies, government research funding agencies, and autonomous organizations or committees. Each member country fulfills two main roles, which it enacts through its NMO. The first of these involves the governance of the institute through its representative Council Member for IIASA, while the second requires the NMO to act as a link between IIASA and national stakeholders.

IIASA National Member Organizations & Council Members

On 31 December 2017 IIASA had 25 member countries (2 x observers), represented by the following National Member Organizations:

Membership of IIASA

The IIASA Charter stipulates that membership of the institute is open to one professional institution from any country as long as it represents the relevant scholarly community of that country, subscribes to the IIASA Charter, and meets the financial obligations of membership. The IIASA Council votes on each country's application to join IIASA and on whether to discontinue a country's membership. In November 2017, Council voted to change India's membership status to observer, with the option to become a full member again as soon as outstanding membership dues are settled. Council also thanked Australia, represented by the Commonwealth Scientific and Industrial Research Organization (CSIRO), for its contribution to IIASA as a member since 2013 and noted, with regret, CSIRO's decision not to continue its membership in 2018. In December 2017, the IIASA Council agreed to accept Israel as a new member country represented by the Israel Committee for IIASA.

AUSTRALIA The Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Council Member: Dr. Peter Mayfield

AUSTRIA The Austrian Academy of Sciences (OEAW)
Council Member: Professor Dr. Gerhard Glatzel

BRAZIL The Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES)
Council Member: Professor Concepta (Connie) McManus Pimentel

CHINA National Natural Science Foundation of China (NSFC)
Council Member: Professor Congqiang Liu

EGYPT Academy of Scientific Research and Technology (ASRT)
Council Member: Professor Mahmoud M. Sakr

FINLAND The Finnish Committee for IIASA
Council Member: Dr. Lea Kauppi

GERMANY Association for the Advancement of IIASA
Council Member: Professor Dr. Helga Weisz

INDIA (Observer) Technology Information, Forecasting and Assessment Council (TIFAC)
Council Member: Professor Prabhat Ranjan

INDONESIA Indonesian National Committee for IIASA
Council Member: Professor Dr. Kuntoro Mangkusubroto

IRAN Iran National Science Foundation (INSF)
Council Member: Professor Nosratollah Zargham

ISRAEL Israel Committee for IIASA
Council Member: Professor Moti Herskowitz

JAPAN The Japan Committee for IIASA
Council Member: Professor Dr. Kazu Takemoto

KOREA, REPUBLIC OF National Research Foundation of Korea (NRF)
Council Member: Dr. Moo Je Cho

MALAYSIA Academy of Sciences Malaysia (ASM)
Council Member: Professor Datuk Dr. Asma Ismail

MEXICO Mexican National Committee for IIASA
Council Member: Dr. Julio A. Santaella Castell and Dr. Enrique Cabrero Mendoza

NETHERLANDS Netherlands Organization for Scientific Research (NWO)
Council Member: Professor Dr. Stan Gielen

NORWAY The Research Council of Norway (RCN)
Council Member: Dr. Kirsten Broch Mathisen

PAKISTAN (Observer) Pakistan Academy of Sciences
Council Member: Professor Dr. Kauser Abdulla Malik

RUSSIA Russian Academy of Sciences (RAS)
Council Member: Academician Alexei Gvishiani

SOUTH AFRICA National Research Foundation (NRF)
Council Member: Dr. Dorsamy (Gansen) Pillay

SWEDEN The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS)
Council Member: Dr. Ingrid Petersson

UKRAINE Ukrainian Academy of Sciences
Council Member: Academician Professor Dr. Anatoly G. Zagorodny

UNITED KINGDOM Research Councils of the UK
Council Member: Professor Duncan Wingham

UNITED STATES OF AMERICA The National Academy of Sciences (NAS)
Council Member: Professor Dr. Michael Clegg

VIETNAM Vietnam Academy of Science and Technology (VAST)
Council Member: Professor Dr. Ninh Khac Ban

The IIASA Council

As the governing body of the institute, the IIASA Council is composed of one permanent representative from each NMO. The Council meets twice a year, in June and November. The Charter and subsequent resolutions of Council document the role of Council, its processes, and decisions.

The Council is responsible for establishing relations with government and international bodies; determining financial and managerial policies and subject areas for IIASA research; and ensuring that IIASA activities are in line with institutional objectives, the provisions of the Charter, and the interests of NMOs.

The Council elects a chair and vice chairs who act as officers of the Council. After serving for three years, Don Saari (United States) stepped down as Council Chair in 2017. Following a nomination and election process, Council appointed Michael Clegg (United States) as the new chair of the Council on 30 September 2017. Gansen Pillay (South Africa) was elected vice chair commencing on 1 January 2018. Pillay takes over from the previous incumbent, Prabhat Ranjan (India), joining Alexei Gvishiani (Russia) who will continue in his capacity as a vice chair in 2018.

The Council appoints the director general and the deputy director general who, as the chief executive officers of the institute, are responsible for implementing the research program and managing the day-to-day operations. In 2012, the Council appointed Professor Dr. Pavel Kabat as the 10th director general of IIASA. Kabat, a Dutch citizen, came to IIASA from Wageningen University in the Netherlands.

The IIASA Council exercises its oversight responsibilities through a committee structure comprising an Executive Committee, a Finance Committee, a Membership Committee, a Program Committee, and an Outreach and Capacity Building Committee. At the end of 2017, membership of these committees was agreed for a new three year period. In addition, an external Science Advisory Committee, and external evaluation committees provide specialized input to Council.

Evaluation and quality control

The IIASA Council oversees an array of activities that support its responsibility to offer guidance and assure the quality and relevance of IIASA research. It serves as a critical element in assuring NMOs of the value of the work done by the institute in return for their contributions.

In 2016, the Council commissioned an institutional review by an independent panel of experts to provide an independent and comprehensive evaluation of IIASA, including all structures, processes, and activities. The review panel aimed to answer the overarching question of whether the general mission and ambitions, the organizational structure and governance, and the scientific programs and their policy-relevant implications, are fit-for-purpose and future-proof.

Following the delivery of the report in June 2017, IIASA Council "welcomed the report of the independent Institutional Review of IIASA and its recommendations to further strengthen IIASA's unique strengths and global reach." The report urged the Council and the director general to "work together to establish a Task Force under Council's leadership to take forward the review recommendations." At the end of 2017, Council appointed Khotso Mokhele and Melody Mentz (both from South Africa) as chair and secretary of the Task Force respectively. The Task Force will commence work in 2018.

Another component of research oversight is the IIASA Science Advisory Committee (SAC). The SAC, established by the IIASA Council in 2002, comprises 15 international experts in fields relevant to IIASA research and its science to policy portfolio. The SAC has an academically and geographically diverse membership—based partly on nominations from NMOs—and includes experts in the main areas of IIASA research. In 2017 its role continued to be to provide independent, expert advice to the IIASA Council and Directorate to ensure that the institute's work continues to meet the highest scientific and policy-relevance standards. In particular, SAC assessed ongoing crosscutting activities of IIASA.

IIASA Governance and Decision Making Structure and its External Advisory Bodies

IIASA Internal Organization Structure
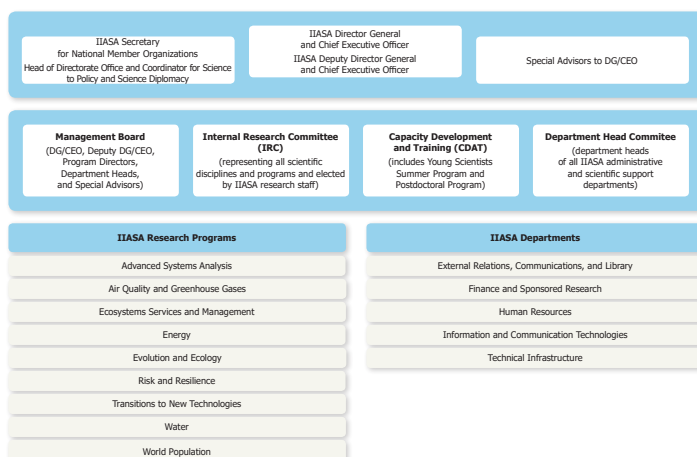
IIASA Management

IIASA is currently structured into nine research programs and five departments that support the institute's scientific activities. In April 2017, the new position of Head of the Directorate Office was established and Jan Marco Müller was appointed to this role. The Directorate Office manages the office of the director general, and oversees Council relations in collaboration with the External Relations, Communications, and Library (ERCL) department. In addition, it provides conference and visitor services for institute-wide events, exercises oversight over the Exploratory and Special Projects program, and coordinates science to policy and science diplomacy activities.

Council Committee Membership

On 31 December 2017 the Council Committee membership was as follows:

Michael Clegg, **Council Chair**
Alexei Gvishiani, **Vice Chair**
Prabhat Ranjan, **Vice Chair**

Executive Committee
Michael Clegg (Council Chair)
Alexei Gvishiani (Vice Chair)
Prabhat Ranjan (Vice Chair)
Gerhard Glatzel
Helga Weisz
Kazu Takemoto
Kirsten Broch Mathisen
Kuntoro Mangkusubroto*
Duncan Wingham*
* For one year (until 31 December 2017)

Finance Committee
Gerhard Glatzel (Chair)
Ingrid Petersson (Vice Chair)
Asma Ismail
Gansen Pillay

Membership Committee
Helga Weisz (Chair)
Stan Gielen (Vice Chair)
Mahmoud Sakr
Anatoly Zagorodny

Program Committee
Kazu Takemoto (Chair)
Concepta (Connie) McManus Pimentel (Vice Chair)
Moo Je Cho
Lea Kauppi
Nosratollah Zargham
Duncan Wingham

Outreach, Capacity Building, and Science Engagement Committee
Kirsten Broch Mathisen (Chair)
Congqiang Liu (Vice Chair)
Ninh Khac Ban
Kuntoro Mangkusubroto
Enrique De Alba/Julia Taguena
Peter Mayfield

Science Advisory Committee

On 31 December 2017 the Science Advisory Council membership was as follows:

Professor Mary SCHOLES – Chair
Wits University
Johannesburg, South Africa

Dr. John R. BIRGE
The University of Chicago Booth School of Business
Chicago, IL, USA

Professor Dr. Mirjam DE BRUIJN
African Studies Centre
Leiden, Netherlands

Professor Ruth DEFRIES
Department of Ecology, Evolution, and Environmental Biology
Columbia University
New York, NY, USA
Professor Bojie FU
Research Center for Eco-Environmental Sciences
Chinese Academy of Sciences
Beijing, P.R. China

Professor Nils Petter GLEDITSCH
Peace Research Institute Oslo (PRIO)
Oslo, Norway

Professor Jim HALL
Oxford University
Oxford, UK

Dr. Kil-Choo MOON
University of Science and Technology
Yuseong-gu, Daejeon, Korea

Dr. Youba SOKONA
The South Centre and the University of Surrey
Geneva, Switzerland

Professor Mari Elka PANGESTU
University of Indonesia and Centre for Strategic and International Studies
Jakarta, Indonesia

Professor Silvia Elena GIORGULI SAUCEDO
El Colegio de Mexico
Mexico

Professor Roberto SCHAEFFER
Federal University of Rio de Janeiro
Rio de Janeiro, Brazil

Professor Dr. Igor SHEREMET
Bauman Moscow State Technical State University
Moscow, Russian Federation

Professor Dr. Karen Helen WILTSHIRE
Alfred Wegener Institute for Polar and Marine Research
Helgoland, Germany

Professor Tetsuzo YASUNARI
Research Institute for Humanity and Nature (RIHN)
Kyoto, Japan

GOVERNANCE & COMPLIANCE

Compliance

IIASA attaches great importance to compliance with various laws, policies, and procedures to ensure that its activities are in line with its objectives, the provisions of its Charter, and the interests of its member organizations.

Health, safety, and wellbeing

IIASA complies with the Luxembourg Declaration on Workplace Health Promotion and the Austrian Employee Safety Law (Arbeitnehme-rInnenschutzgesetz). These laws stipulate that an occupational health doctor must be employed by the institute. IIASA has been working with a general practitioner qualified in occupational medicine since 1997, and in 2017 also added an occupational psychologist to its staff.

In addition to Austrian Safety Law, which covers work equipment, materials, and employee health, and includes regulations on topics like the position (height and distance) of the computer screen, the adjustment (height and positioning) of the chair, the height of the desk, lighting, and the ergonomically appropriate set up of offices, IIASA also adheres to:

- The Bildschirmverordnung, which regulates work with computers/ screens
- Regulations regarding the training of first aid officers and first aid equipment
- Regulations regarding the appointment of a safety specialist
- Regulations regarding the protection of non-smokers

IIASA is legally required to report work-related accidents. In 2017 no notable incidents were reported.

The institute has guidelines regarding the following Health and Safety issues (detailed in the IIASA Handbook):

- Maternity regulations
- On-duty accidents
- Fire prevention
- Smoking
- Prevention of health risks while working with computers

In Austria, these guidelines all fall under the legal framework regarding Health and Safety in the work place (i.e., ArbeitnehmerInnenschutzgesetz, Mutterschutzgesetz, Bildschirmverordnung).

IIASA started working with a new external safety services company in 2017. This company provided a specialist to support the institute's doctor and psychologist to evaluate and document the implementation of the laws and guidelines listed above. In addition to this, the company also helped to devise strategies for improving employee health at work, with a specific focus on workplace safety (Arbeitsplatzsicherheit).

During 2017, the institute doctor and safety specialist conducted workplace inspections with about 120 employees during which staff had the opportunity to talk about work-related stress and strain experienced at the workplace.

Risk management

Risks are always considered and managed for at IIASA when individual management decisions are made. However, in the interest of more systematically assessing mid- and long-term risk along with the appropriateness of IIASA measures to mitigate risks, Council commissioned a review of the institute's governance, compliance, and assurance processes, including risk management. A governance and compliance expert from the South African National Member Organization conducted this review and reported the findings to Council in June 2017. Subsequently, Council requested IIASA to develop a risk register to more systematically manage risk at IIASA. The risk register is currently being developed and will be presented to Council in June 2018.

Operating rules and procedures

In 2016, IIASA reviewed all documented operating rules and procedures to identify items that needed to be updated, better documented, or both. During 2017, the administrative and support departments worked on revising, and where necessary, updating the aspects identified in the review phase. New guidelines and regulations were also drafted to ensure transparency, accessibility, and best practice. This process will continue in 2018.

GOVERNANCE & COMPLIANCE

Financial policies and procedures

The Finance Committee of Council supervises the institute's accounting and auditing activities, annual payments of National Member Organization contributions, the realization of royalties and other revenues, and annual financial reports. IIASA is also legally obliged under the Austrian Association Act and Austrian commercial law to have its accounts externally audited on an annual basis. IIASA's statutory financial statements will be audited by BDO Austria.

In addition, some external funders require that the projects they contribute to are individually audited. The European Commission (EC), a major contributor to the institute's external funding, also sometimes performs second-level audits on already externally audited EC projects. To date, four major second-level audits on twelve projects were carried out in 2009, 2011, 2015, and 2017 respectively. All of these were successfully concluded.

At IIASA, financial policies and procedures are in place for:

- Sponsored research and budgeting for proposals (sections 4.4.7 and 4.4.8 of the IIASA Operating Procedures and Policies)
- Procurement, business travel, organizing conferences, and visits from external collaborators and stakeholders (section 4.4 of the IIASA Operating Procedures and Policies)
- A budget planning and oversight process as shown in the diagram below (section 4.4.2 in IIASA Operating Procedures and Policies)

The procedures and approval processes are facilitated and documented through the IIASA Management Information System.

Infrastructure development

In May 2017, 70 IIASA staff members took part in the annual Austrian bike to work initiative, which aims to encourage more sustainable commuting options. This was the fourth year that IIASA staff participated in the initiative, with increased participation and interest from staff members seen year on year. Together, the IIASA teams rode more than 15,000 kilometers–the second most of any company or organization taking part in the 2017 campaign.

A number of refurbishments also took place in IIASA buildings over the course of the year. These included measures to enhance resource efficiency.

In addition to the above, the IIASA Staff Association (STAC) formed an Environmental Committee for 2018 that will focus on nurturing more environmentally friendly processes, practices, and activities at the institute in the future.

Legal compliance

IIASA is legally registered as "Verein" (Association) in Austria with registration number (ZVR-Nr 524808900) and is subject to the laws and jurisdiction of its host country, Austria. These include all laws that typically affect an organization of similar size, such as:

- IIASA as a "Verein": Austrian Association Act
- IIASA as an organization with an annual income over €20 million: Austrian Commercial Law
- IIASA as an employer: Austrian Labor Law; Austrian Health and Safety Acts and regulations; Austrian Social Insurance Law including specific agreements for IIASA
- IIASA as a publisher and provider of research material: Austrian Media Act; Austrian E-Commerce Act; Austrian Copyright Law; Austrian Intellectual Property Law
- IIASA as a holder of information about people: Austrian Privacy Law; Austrian Data Protection Act

Environmental performance

In May 2017, 70 IIASA staff members took part in the annual Austrian bike to work initiative, which aims to encourage more sustainable commuting options. This was the fourth year that IIASA staff participated in the initiative, with increased participation and interest from staff members seen year on year. Together, the IIASA teams rode more than 15,000 kilometers–the second most of any company or organization taking part in the 2017 campaign.
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In addition to the above, the IIASA Staff Association (STAC) formed an Environmental Committee for 2018 that will focus on nurturing more environmentally friendly processes, practices, and activities at the institute in the future.

Copyright and data security

Intellectual property and copyright

IIASA follows the rules and procedures laid out in the institute's Patent and Software policies. The Patent Policy ensures that any invention made in the course of the research activities at IIASA is used to bring about the widest possible benefits. This includes that the institute gains financially from any commercial exploitation of patents resulting from the use of its resources, and that favorable terms are applied in granting licenses to organizations and citizens of National Member Organization countries. The Software Policy defines and protects the intellectual property rights for software that has been developed by IIASA staff, and outlines the processes for commercialization, licensing, and distribution.

IIASA follows the rules and procedures laid out in the institute's Copyright Policy. This takes into consideration the practices of international journals and publishers, and aims to facilitate the widest possible dissemination of IIASA results. In 2017, as part of the internal review of all policies at IIASA, the External Relations, Communications, and Library Department began updating the Copyright Policy, taking into account the latest developments in academic publishing, open access publishing, and the use of creative commons licenses to expand the sharing and uptake of IIASA research.

Information technology and data security

The Information and Communications Technologies (ICT) Department provides the complete range of IT services essential to IIASA with a necessary focus of reliability and security. To ensure that ICT resources at IIASA keep pace with the ever-growing needs of scientific research, the Head of ICT chairs the ICT Forum. This ICT Forum serves as an advisory and steering body providing a critical link between the ICT Department and the scientific programs. As a result of the guidance provided by the ICT Forum in 2017, the IIASA scientific IT portfolio was expanded to include LINUX-based scientific computing capabilities in addition to its existing Microsoft Windows and Solaris UNIX-based facilities. A new 250 terabyte data storage system was also installed to continue servicing the growing data storage needs of the institute's research efforts. This new system expands the total data storage capacity of IIASA to more than 450 terabytes with the potential to go beyond two petabytes.

Data management and archive policies

The IIASA rules laid out in its policies on Good Scientific Practice and Conflict of Interest, constitute the institute's current data archiving standard.

To comply with the requirements of research funders and other collaborators, IIASA policy stipulates that all primary research data must be retained for a minimum of 10 years, thus ensuring the reproducibility of findings and results. In addition, model-based work, model specifications, and methods of analysis have to be sufficiently documented, ideally in a peer-reviewed publication or its official supplement.

To expand and formalize this policy, the Open Access to Data Task Force, which is comprised of researchers, the IIASA Library team, and IT experts, continue their deliberations. In 2017, this taskforce took stock of the status of data and research tools, and produced two separate inventory catalogues detailing all IIASA datasets, software, tools, and models to include access links to relevant details. In conjunction with the IIASA Library, the taskforce established a prototype Data Repository based on the same technology as the institute's highly successful Publications Repository (PURE). An improved Research Data Management policy, which is necessary to ensure the long term archival and open availability of IIASA's wealth of datasets, models, and tools, has also been drafted and is currently under review. The goal is to fully implement the new policy in 2018.

Data protection and privacy

As a publisher and provider of research, IIASA is subject to the Austrian Media Act, the Austrian E-Commerce Act, Austrian Copyright Law, and Austrian Intellectual Property Law.

The institute is the custodian and processor of personal data concerning both its staff and other individuals associated with the institute. The institute periodically sends bulk mails to some of its contacts for a variety of reasons, ranging from asking them to attend an event, to encouraging them to use IIASA research.

In light of the above, the institute is obligated to follow the provisions of Austrian Data Protection Law (e.g., Datenschutz-Grundverordnung (DSGVO)). In turn, as a member of the European Union, Austria has to ensure that the DSGVO complies with the new EU General Data Protection Regulation (GDPR), which comes into effect on 25 May 2018.

Financials

The institute's annual budget in 2017 was €21 million, of which 58% was from research funding agencies in member countries in Africa, the Americas, Asia, Europe, and Oceania. These diverse sources of income enable IIASA to perform research that is truly independent.

In 2017, IIASA continued its strategy of increasing investment in its research activities that began in 2011. This saw expenditure on research and scientific services grow by €1.4 million from just under €16 million in 2016, to €17.4 million in 2017. Since 2011 there has been an increase of 41% in research and scientific services. In 2017, the expected income, mainly from IIASA membership contributions, did not materialize as budgeted, hence IIASA had to draw on its financial reserves. After the closure of 2017, the reserves however remain at a strategic level of circa 25% of the annual budget.

The institute receives additional funding from contracts, grants, and donations from governments, international organizations, academia, businesses, and individuals. Between 2012 and 2017, this additional funding amounted to €52 million. This is part of a funding portfolio of €265 million — the total awarded to external projects featuring collaborations between IIASA and its member countries.

Research Funding Agencies:

In 2017 IIASA membership contributions were provided by the following agencies:

- The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia
- The Austrian Academy of Sciences (OEAW)
- The Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES)
- National Natural Science Foundation of China (NSFC)
- Ministry of Finance, Egypt
- Academy of Finland
- Federal Ministry of Education and Research (BMBF), Germany
- Ministry of Foreign Affairs, Indonesia
- Ministry of Finance, Japan
- National Research Foundation of Korea (NRF)

- Accountant General's Department of Malaysia
- National Council for Science and Technology (CONACYT) and National Institute of Statistics and Geography (INEGI), Mexico
- Netherlands Organization for Scientific Research (NWO)
- The Research Council of Norway (RCN)
- Russian Academy of Sciences (RAS)
- National Research Foundation (NRF), South Africa
- The Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS)
- Ukrainian Academy of Sciences
- Economic and Social Research Council (ESRC), Engineering and Physical Sciences Research Council (EPSRC), and Natural Environment Research Council (NERC), UK
- National Science Foundation (NSF), USA
- Vietnam Academy of Science and Technology (VAST)

Donations

The YSSP Fund provides funds for a scholarship that is awarded to promising young researchers without National Member Organization support, often from developing countries, to take part in the institute's three-month Young Scientist Summer Program (YSSP). Generous donations from IIASA supporters enabled four exceptional young scientists to participate in the 2017 YSSP.

The Peter E. de Jánosi Postdoctoral Fellowship fund, set up in honor of former IIASA director, Dr. de Jánosi, offers selected postgraduate students the opportunity to participate in the IIASA Postdoctoral Program.

A donation to the Howard Raiffa Fellows Program in Decision Science preserves the legacy of the first IIASA director and brings distinguished scientists in this field to IIASA to work on the global problems addressed by the institute's research programs.

The institute continues to receive generous support through the non-governmental organization Friends of IIASA, which enables US residents to make tax deductible donations to the institute.

IIASA thanks all donors for their generosity in 2017 and is grateful for their commitment and belief in the mission of the institute.

FINANCIALS

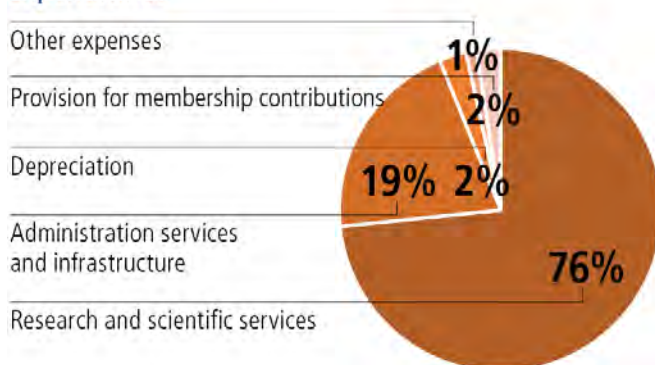|	31-DEC-17 (€)	31-DEC-16
INCOME		
Membership contributions (I)	12,317,700	12,405,500
Contracts and grants (II)	8,395,675	8,976,741
Other income	423,441	659,460
TOTAL INCOME	21,136,816	22,041,701
EXPENDITURES		
Research and scientific services	17,365,998	15,966,713
Administrative services and infrastructure	4,396,288	4,447,599
Depreciation	541,280	590,135
Other expenses	323,914	230,196
Provision for membership contributions	350,000	523,500
TOTAL EXPENDITURE	22,977,480	21,758,143
Change in net assets	-1,840,664	283,558

(I) Expected income from membership contributions in 2018 according to budget: €13.2m

(II) Expected income from contracts and grants in 2018 according to budget: €9.0m

Income

2% Other income
58% Membership contributions
40% Contracts and grants

Expenditures

Other expenses 1%
Provision for membership contributions 2%
Depreciation 2%
Administration services and infrastructure 19%
Research and scientific services 76%
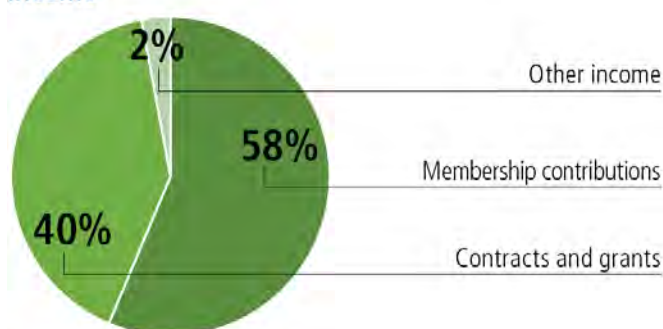
	31-DEC-17 (€)	31-DEC-16
NON-CURRENT ASSETS		
Property, plant, and equipment	906,787	1,045,089
TOTAL NON-CURRENT ASSETS	906,787	1,045,089
CURRENT ASSETS		
Inventories	25,340	25,820
Work in progress	1,453,230	1,717,401
Receivables and prepayments	4,793,116	4,753,065
Cash and cash equivalents	9,152,759	11,863,364
TOTAL CURRENT ASSETS	15,424,445	18,359,650
TOTAL ASSETS	16,331,232	19,404,739
Assets held in trust	12,719,350	11,882,998

	31-DEC-17 (€)	31-DEC-16
NET ASSETS		
Restricted funds	914,464	1,052,766
Unrestricted funds	5,586,378	7,273,019
TOTAL NET ASSETS	6,500,842	8,325,785
NON-CURRENT LIABILITIES		
Provisions	2,493,895	2,470,220
TOTAL NON-CURRENT LIABILITIES	2,493,895	2,470,220
Prepayments	4,622,116	5,519,726
Provisions	1,506,118	1,421,103
Other liabilities	1,208,260	1,667,905
TOTAL CURRENT LIABILITIES	7,336,494	8,608,734
TOTAL LIABILITIES	9,830,389	11,078,954
TOTAL LIABILITIES & NET ASSETS	16,331,231	19,404,739
Trust liabilities	12,719,350	11,882,998

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Publications and open access

2017 publications

In 2017, there were 611 IIASA publications, of which 396 were peer-reviewed journal articles. These articles were written in collaboration with over 1,600 coauthors from 159 institutions in 65 countries and regions.

IIASA has a Scientific Publications Policy that encourages the widest possible dissemination of work done by its researchers. In 2016, IIASA also introduced an open access policy to make all publications freely available via its publications repository (PURE).

The policy requires that all IIASA authors deposit a complete version of their peer-reviewed research articles in the IIASA institutional repository, to ensure that it is freely accessible within a year of the online publication date. This can either be the published version of the paper (known as gold open access), or the accepted version of the paper (known as green open access).

During 2017, the IIASA Library negotiated an agreement with the Taylor & Francis Group to facilitate access and additional open access publishing at no extra cost. This is one of several agreements with publishers that allow for a discount on article processing charges, or enable open access publishing without additional costs for authors affiliated with IIASA. Agreements with MDPI, for example, allow authors to publish at discounted charges, while IIASA's agreement with Springer, which has been in place since 2016, allows corresponding authors affiliated with IIASA to publish open access at no extra cost. These agreements have enabled the publication of over 50 open access articles. In addition to the above, a new 'read & publish' agreement was negotiated with Wiley during 2017. This agreement, which will be effective as of 2018, grants access to not only journals, but also to unlimited open access publications in hybrid journals at no extra cost.

Because IIASA encourages its researchers to publish their research in journal articles or books that are available free of charge to all users (gold open access), it has established a fund for covering open access fees. In 2017, this fund was made available to researchers to partially cover publication costs if no other grant is available. This facilitated the publication of 27 articles through gold open access.

Of the 396 journal articles published in 2017, 242 have publicly available full text in PURE. A total of 80 full texts are currently still under embargo (34 for 12 months or less), and 74 entries have no paper attached. As of January 2018, compliance to the IIASA Open Access Policy in 2017 was 70%. An increase in this rate is foreseen for 2018.

In 2017 there were 252,129 downloads from PURE, compared to 87,900 between March and December 2016 (the repository only went live in March 2016). Apart from increasing the visibility of IIASA research, PURE
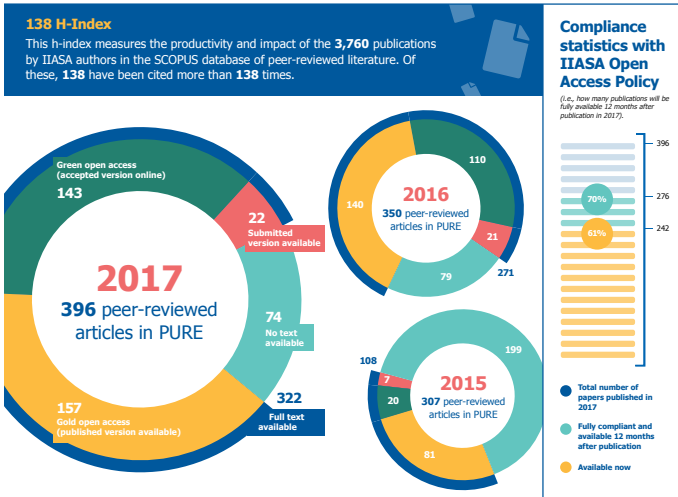
also facilitates the linking of all publications related to a specific project to improve reporting to funders, the tracking of research output, and the aggregation of content that feed into aggregating services like OpenAIRE.

In addition to the traditional metrics currently used in academia to determine research impact, the Altmetrics widget included in PURE monitors mentions of IIASA publications in news outlets and social media, and has become a popular tool for supplementary information on the performance of individual publications.

During 2017, work also began on updating the Scientific Publications Policy and Copyright Policy to bring them in line with current practices.

Open access to data

The open access to data taskforce was set up to conduct an analysis of the current status of open access to data, research tools and models at IIASA, along with future options for discussion by the Council.

In 2017, the taskforce produced an inventory of all datasets, software, tools, and models available

at IIASA with links for accessing them, as well as further links to relevant publications and other related projects. This inventory was provided to the Council in June 2017 and followed up with an updated version in November 2017.

Based on the software used for the publications repository (PURE), work on establishing an IIASA Data Repository started in 2017. A prototype was set up and tested internally, after which the library

team began populating it. A live implementation along with a Research Data Management Policy – which was drafted in 2017 and is currently under internal review – is planned for 2018.

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ABOUT IIASA

The International Institute for Applied Systems Analysis (IIASA) is an independent, international research institute with National Member Organizations in 23 countries in Africa, the Americas, Asia, and Europe. Through its research programs and initiatives, the institute conducts policy-oriented research into issues that are too large or complex to be solved by a single country or academic discipline. This includes pressing concerns that affects the future of all of humanity, such as climate change, energy security, population aging, and sustainable development. The results of IIASA research and the expertise of its researchers are made available to policymakers in countries around the world to help them produce effective, science-based policies that will enable them to face these challenges.

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