IIASA RESEARCH PLAN 2016–2020

Systems Approaches for Global Transformations

International Institute for
Applied Systems Analysis
www.iiasa.ac.at

Foreword

Our world is changing at an unprecedented rate. The challenges of rapid globalization, radical shifts in economic and political power, pressing environmental problems, and geopolitical conflicts require a global transformation.

IIASA is uniquely positioned to respond to these challenges. As a leader in applied systems analysis, the institute is able to integrate natural, social, and economic systems to produce independent, interdisciplinary research into real-world problems. The institute's collaborations with research institutions and policymakers around the world ensures the highest quality, most relevant science.

However, rapid global changes also require research institutions to adapt, seeking new solutions to new issues. This new *Research Plan* provides both the foundation for the institute's research direction over the next five years, and the necessary flexibility to accommodate changing scientific or policy priorities.

To arrive at this forward-thinking plan, IIASA sought input from a broad spectrum of its researchers and high-level stakeholders. An extended IIASA Council meeting, where National Member Organizations discussed new research directions, was held in June 2015, and this was complemented by several retreats, with program directors, senior research staff, and mid-career IIASA researchers, to revise and refine the plan. The IIASA Science Advisory Committee also reviewed the plan.

The new plan moves away from the idea that problems (such as climate change) are separate from drivers (such as population growth) or from impacts (such as environmental degradation). Problems, drivers, and impacts are in fact closely related elements of systems analysis and achieving true sustainability requires an approach that can link diverse dynamic systems.

The first five years of research under the IIASA 2011-2020 Strategic Plan has had substantial impact, shaping policy at national, regional, and global scales (as shown in *Research for a Changing World: IIASA Highlights 2011-2015*). Distinguishing features in this *Research Plan* include, among others, enhanced emphasis and investment in cross-cutting research, a new focus on futures initiatives, as well as large-scale, integrated "nexus" projects. In the coming five years IIASA will also increase intellectual and financial investment into new methods in systems analysis. This will create a future in which IIASA continues to lead in systems analysis approaches that can help to achieve tomorrow's solutions to today's challenges.

Professor Dr. Pavel Kabat
Director General and CEO

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IIASA Council Chair

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Global transformations, systems approaches, and the IIASA niche

Today's world is undergoing a major transformation, characterized by increased globalization, fundamental shifts in economic and political power, growing global environmental problems, and potentially explosive social and geopolitical conflicts.

Concerted global, regional, and national efforts over the last two decades have substantially improved human wellbeing. Over this period, extreme poverty has declined significantly to a point where now, for the first time in history, less than 10% of the world's population live in extreme poverty; global child and maternal mortality rates have halved; almost 2 billion people have gained access to safe drinking water; the number of children receiving basic primary education has increased significantly; and life expectancies have increased dramatically worldwide. At the same time, the world economic product has increased to about US$14,000 Purchasing Power Parity (PPP) per person, which, if equally distributed, would be high enough to allow for the worldwide fulfillment of basic human needs.

Despite these successes, the gap between the richest and poorest households and between rural and urban areas has widened, gender inequality still persists, and millions of people still live in poverty and hunger, without access to basic services. Regional environmental impacts are increasing, and climate change and biodiversity loss have become global problems. Furthermore, the interdependencies among nations and economies have created new risks and vulnerabilities, as demonstrated by the ongoing global financial crisis, increasing geopolitical complexity and uncertainty and associated mass migration, and the persistent threat of pandemic and emergent diseases. Human conflicts also remain a major threat to human development.

More and more, economic, social, technological, and environmental systems are becoming highly interconnected and interdependent. As a result, decision makers and stakeholders around the world are increasingly asking for the improved understanding of complex problems and comprehensive solutions that can only be obtained through interdisciplinary models and analysis. They also expect solutions for short- and long-term horizons, for interconnected sectors, and for the local, national, regional, and global spatial scales. They may not know it, but they are asking for solutions based on systems analysis.

In this global context, and with its history as a leader in applied systems analysis, IIASA is uniquely positioned to respond to these demands. Increasingly, IIASA is integrating natural, social, and economic systems, and is seeking to change the global narrative away from regarding these global challenges as threats, but rather as potential opportunities for sustainable solutions. IIASA has a track record of delivering global, regional, and national impact through conducting excellent, independent, interdisciplinary research into real-world problems, often in collaboration with large international research and analysis networks, and working with policy and decision makers to identify and assess possible solutions. In addition, the institute is truly international, having members in both developed and emerging economies, and has the capacity for bringing together people from all over the world. Some selected highlights of IIASA achievements in these areas are provided in Appendix 1.

IIASA strengths

A core strength of IIASA is its leadership in applied systems analysis, which is:

PROBLEM-DRIVEN AND SOLUTION-ORIENTED Improving the understanding of global challenges and assessing options to assist decision making by policymakers.

INTEGRATED AND INTERDISCIPLINARY Considering a broad range of options and impacts as well as the dynamic interactions among multiple affected systems and their interlinkages, including a wide range of academic disciplines.

SCIENCE-BASED Using the best science, approaches, models, databases, and tools to provide a foundation for sound analysis.

INDEPENDENT AND INTERNATIONAL Using its unique position as a truly international body that is neutral, independent of governments, commercial organizations, and other interest groups, to produce results that are both pertinent to world problems and based on complete scientific integrity.

Systems analysis research at IIASA is characterized by emphasizing:

INTERACTIVE DYNAMICS OF COMPLEX SYSTEMS Systems analysis contributes to understanding the interactive dynamics characterizing complex human-environment systems, including discontinuities and critical thresholds.

LONG-TERM TRENDS AND TRANSFORMATIONS Many global challenges faced by humanity have evolved over very long time spans. In some cases—mitigation of climate change, for example—time lags between action and consequences extend beyond several human generations.

RISKS AND UNCERTAINTIES Many global problems involve substantial risks and often deep uncertainties, which make it hard to predict the consequences of policies. Systems analysis addresses these risks and uncertainties and examines appropriate alternative policy responses, including robust solutions, adaptive decisions, and resilient strategies.

GUIDANCE AND GOVERNANCE Systems analysis provides guidance to policymakers by offering high-quality models, data, and analyses in a format that decision makers and stakeholders themselves can use to explore problems and solutions.

GLOBAL RESEARCH WITH REGIONAL AND NATIONAL IMPLICATIONS Global systems analyses are closely linked to regional and national solutions. This is accomplished by conducting regional or national case studies in cooperation with national centers of excellence (partner institutions and National Member Organizations).

Strategic context

In January 2011, IIASA embarked on the implementation of its 10-year (2011–2020) Strategic Plan – *Research for a Changing World*. The plan articulated an ambitious strategy to realize the institute's mission of "*providing insights and guidance to policymakers worldwide by finding solutions to global and universal problems through applied systems analysis in order to improve human and social wellbeing and to protect the environment*" and thereby cementing its position as a world leader in systems analysis.

This 10-year timeline was divided into two five-year research planning periods, the first of which (2011–2015) finishes this year. Much has been accomplished over this period, as outlined in the publication *Research for a Changing World - IIASA Highlights 2011-2015*. All IIASA research programs have been subject to external, independent, international evaluation over this time, and all have received very positive reviews, indicating that IIASA remains well on-track towards accomplishing its vision. The new IIASA cross-cutting projects and Futures Initiatives are also beginning to gain traction and deliver significant results. However, there is still much to be done to achieve the objectives set in 2011.

Meanwhile, the world around us has changed. Although many of the global challenges and required transformations articulated in the current IIASA Strategic Plan are still, and arguably even more, relevant today, new challenges are emerging. These will increase the need for science, and systems analysis in particular, and place increased demand on research institutions to respond. Notably, the recent adoption by the UN of the 17 Sustainable Development Goals, has once again catapulted sustainable development, in its broadest form, back onto the research agenda, and the 2015 climate agreement has increased the need for scientifically robust and policy-relevant inputs. Both of these fall directly within the remit of the IIASA problem-driven and solution-oriented systems analysis approach. In addition, rapidly evolving, non-traditional global governance and economic systems, and increasing geopolitical complexities (including the socioeconomic impacts of the current mass migration of people from conflict regions), present added challenges for both science and policy.

IIASA is no longer a "big fish in a small pond" of international interdisciplinary institutions working on global challenges. Over the last decade, a number of internationally recognized institutions and initiatives aiming to tackle similar questions have emerged. IIASA must strategically and actively engage with this growing network to ensure that its research remains both competitive and relevant, as well as delivering globally significant solutions.

IIASA itself has also changed significantly over the last five years. The number of member countries has grown from 17 in 2009 to 23 in 2015, and are expected to increase again in the next two years. Today, these 23 countries account for over two-thirds of the global population and include the world's four largest economies. While providing IIASA with significantly increased financial stability, this growth also entails an increase in the magnitude and diversity of the member countries' expectations of IIASA.

While accepting that IIASA is mid-way through the implementation of its 2011-2020 Strategic Plan, the changing external and internal landscape has prompted the institute to begin revising its strategic outlook beyond 2020, to provide an up-to-date strategic framework for the Research Plan 2016–2020. As such, the text that follows includes descriptions of both current research activities that will continue or be strengthened, and new activities that will be initiated during the next five years, to meet the new strategic objectives.

Research framework and focus

There are many interconnected global problems that urgently require all sectors of society to work together to develop integrated and sustainable solutions: poverty, hunger, water scarcity, energy security, climate change, land-use changes, natural disasters, biodiversity loss, economic crises, environmental degradation, international conflicts, and terrorism. Other problems are universal in that they are common to many countries and require national solutions: for example, aging populations, migration and immigration, education, traffic congestion, crime, pollution, and health care. Further issues relate to inequities and conflicts: the gap between the rich and the poor, gender and educational inequality, conflicts about the control of resources, and racial and ethnic differences.

IIASA, building on a strong foundation of integrated systems analysis, undertakes research across, and at the intersection of, natural, human, social, knowledge and technology systems, to support development of integrated solutions to these global sustainability challenges (Figure 1). These research directions and portfolios are co-designed and brought to decision makers through partnerships at the interfaces between science, policy, and society.

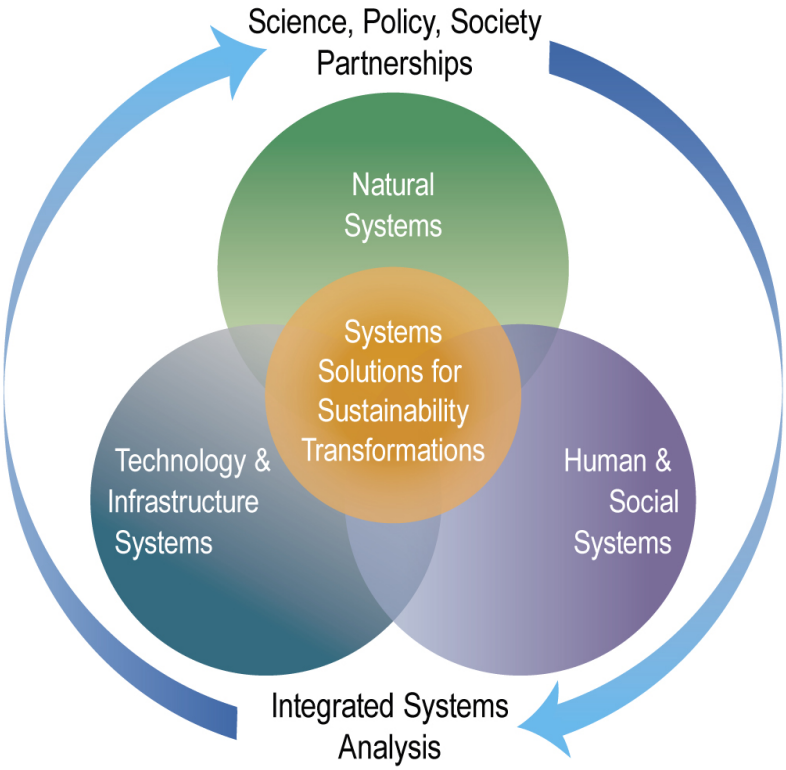

Figure 1. The IIASA Research Framework

The framework differs from that previously used by IIASA, which had separated out specific problem areas (e.g., energy and climate) and their drivers (e.g., economic and population growth) and impacts (e.g., environmental degradation). However, problems, drivers, and impacts are closely related elements of systems analysis. For example, economic growth and environmental quality are intimately linked. The general problem of sustainability in all its dimensions requires a synthetic approach linking diverse complex dynamical systems, a challenge that IIASA is uniquely positioned to address. Based on advances in our scientific understanding, modeling capabilities and interactive policy analysis, it is therefore more appropriate to integrate these drivers and impacts into their relevant systems to enable a more holistic systems analytics approach to developing and evaluating potential solutions.

This framework provides both the foundation for the institute's research direction over the next decade and the necessary flexibility to modify the specific portfolio of IIASA activities to accommodate any changing scientific and/or policy priorities. Importantly, it places at the center IIASA's unique capability for working at the intersection of global systems to develop integrated options and solution pathways for the major transformational challenges towards sustainability.

Within this general framework, the strategic research focus areas at IIASA are represented by Figure 2. The outer circles show the current nine research programs and the proposed new Global Health activities. The inner circle represents integrated research activities at IIASA. Importantly, the diagram shows how each of the research programs intersect and contribute to these integrated projects, which are a significantly increasing focus of the IIASA research portfolio.

The selection of these research areas was based on the following criteria:

- Importance of the research area to the global agenda;
- National Member Organization interest in identifying solutions to the problem; and
- IIASA capabilities to conduct research to identify and assess policy options.

Figure 2. The IIASA research themes

These research themes are clearly very important to many national governments and international organizations around the world. IIASA is uniquely able to tackle this set of issues in a single international, interdisciplinary research institution. One of the most significant advantages of IIASA is the ability to build interdisciplinary teams to undertake research at the intersections of these research themes, such as the nexus between food, energy, water, population, climate, and land use, all within

a science-to-policy framework. This is a truly unique position among international research institutes. Full descriptions and outlooks for each of these research themes are provided later in this research plan.

How IIASA delivers impact

Building on its strengths, and within its overall research framework, IIASA delivers impact globally and to its member countries by helping them to:

1. Better understand and find solutions to complex global issues that are integrally connected to and impinge on the nation's economy, environment, government, and society;
2. Develop the research and science-to-policy base for system analytical approaches through international scientific collaborations, capacity development, and training activities; and
3. Establish new multilateral scientific relationships that contribute to the country's soft power through science diplomacy and scientific input to international negotiations.

The institute achieves this impact primarily by:

- Undertaking large-scale, multi-year integrated projects, spanning all IIASA activities, to analyze the major global transformations;
- Undertaking and publishing world-class, internationally recognized scientific research, through its core research programs, cross-cutting activities and international networks;
- Undertaking small-scale, exploratory projects around emerging research and policy trends;
- Developing new methods in systems approaches, not only in research but also in how that research is delivered both to policymakers and other stakeholders (private sector, civil society);
- Working in partnership with policy and decision makers, globally, regionally, and nationally, to translate this research into robust, plausible policy options;
- Building global capacity in systems analysis and IIASA methods and tools.

The IIASA approach therefore encompasses the full path to impact from problem identification and exploration; through model and tool development and application, data analysis, and capacity development; to the identification of possible policy options and solutions for decision makers.

In addition, IIASA provides a service to the global scientific community through hosting and maintaining a number of databases and models used by scientists and policymakers, and plays an important role in science diplomacy, using science to build bridges across increasingly complex political divides. All IIASA activities are supported by the institute's administration, infrastructure, and services and overseen through its various governance mechanisms.

The various roles of IIASA and its paths to impact are represented in Figure 3, below. Note that the relative sizes of the elements in the diagram **do not** represent relative resource allocations or effort within each role. This remainder of this research plan focuses on these central roles and paths to impact.

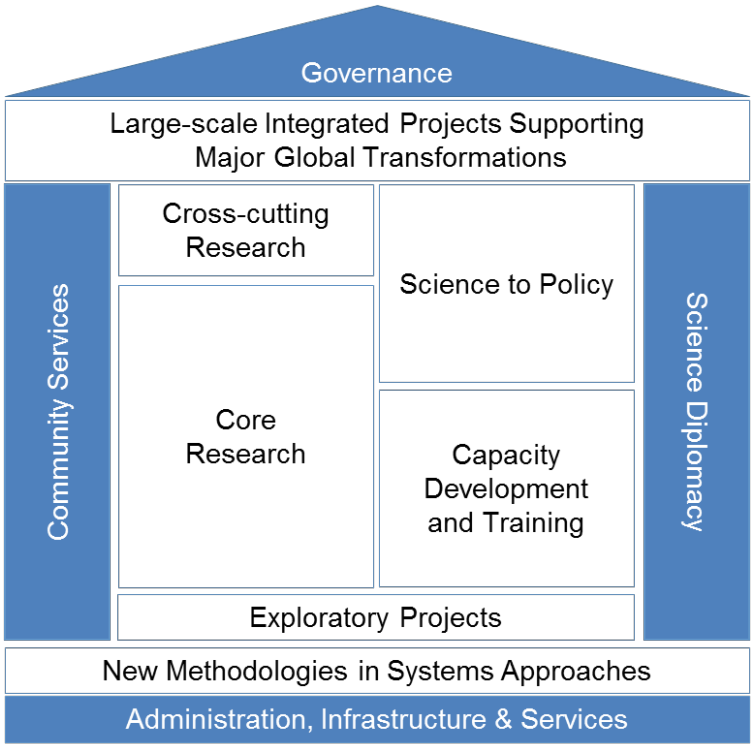

Figure 3. The major roles and pathways to impact of IIASA

Networks and partnerships

The research and outcomes outlined within this plan may be considered very ambitious for an institute the size of IIASA. However, IIASA is much more than a single-campus research institute with relatively modest human and financial resources. In addition to its core research staff (approximately 320 researchers) based in Laxenburg, Austria, IIASA operates as a hub for an active external network of over 2,500 collaborators from over 65 countries. In 2015, over 1,800 members of this network visited the institute. IIASA researchers and their collaborators participate in over 140 external projects and IIASA has nearly 600 partner institutions in over 75 countries. In 2015, IIASA published 213 journal articles collaborating with over 650 coauthors from 160 institutions in 43 countries. Importantly, these networks not only comprise scientists, but also include policy and decision makers across government, non-government, business, and societal sectors. These external networks and partnerships are a critical component and means by which, IIASA delivers impact. In addition, IIASA interacts and actively collaborates with other key players in the global change research community, such as Future Earth and the Belmont Forum.

Global, regional, and national impact

The primary and ongoing role of IIASA is to understand and substantiate major global transitions across environmental, socioeconomic, institutional, and governance arenas. Using global concepts, models, and datasets, the institute's holistic, multidisciplinary research approach produces integrated transitional pathways for many global transitions, which in turn can be downscaled to regional, and often national, scales.

However, to truly understand such global transformations, it is becoming increasingly necessary to understand regional dynamics themselves, particularly of those so-called hotspot regions that are already undergoing rapid transitions across multiple sectors and having a major impact on global systems (e.g., Africa, Arctic, Eurasia, the Middle East, and Southeast Asia).

IIASA can establish a unique scientific niche within these regions. Research related to these regions is typically fragmented and is often sectorally based. There is an alarming lack of independent studies published and communicated to policymakers that propose cross-sectoral, trans-disciplinary, or transboundary solutions. New methods for combining various models, from qualitative to quantitative, and involving stakeholders in the modeling processes, are required for these nexus issues. This will allow exploration of potential synergies and trade-offs across environmental, physical, and socioeconomic sectors, as well as new methods for embedding and nesting these national and regional transitions scenarios into global ones. The IIASA systems analysis approach can play a key role in this endeavor and the institute also has the advantage of being able to identify the common denominators of benefits shared by more than one member country in a particular region.

Many of the economic, environmental, and societal issues facing governments are no longer confined within national borders, but need to be considered in the broader regional and global contexts. In this regard, IIASA is increasingly working with governments and decision makers within its member countries to help identify and implement smart transition pathways in a rapidly changing and increasingly interconnected and complex world. In addition to these strategic, international-level interactions, IIASA also undertakes bilateral projects within member countries to address specific national challenges and conducts case studies to support and substantiate IIASA global and regional models.

Large-scale integrated projects supporting global transformations

Narrowly focused, single-disciplinary science alone cannot adequately underpin policy options and solutions to resolve global sustainability challenges. Multiscale, integrated, interdisciplinary approaches that consider social, economic, and environmental aspects, that look across and between borders and sectors, and that identify feedbacks, trade-offs and co-benefits of a policy or management decision are required. Large-scale, integrated research projects at IIASA seek to address these issues. These projects bring together core expertise from across all of the institute's research programs and external networks, to build truly integrated interdisciplinary teams to address the research objectives at both global and regional scales.

Two major, multi-year, integrated research initiatives will commence in 2016. These two complementary projects are closely connected to each other and to the Nexus++ cross-cut project

(see below). The World in 2050 project and international consortium provides the overarching global research perspective for delivering on sustainable transformations and the Integrated Solutions for Water, Energy, and Land project provides a fast-track, externally funded, pilot study across a subset of sectors in two regions. Finally, the internally funded Nexus++ project seeks to develop the new, integrated methods and approaches required for delivery.

The World in 2050 (TWI2050)

The UN Sustainable Development Goals (SDGs), and their accompanying targets and indicators, provide an aspirational narrative for human development—a world free from hunger, injustice, and absolute poverty but with inclusive and universal economic growth, based on transparency, dignity, and equity. Unfortunately, the world lacks a clear understanding of the cost of inaction and how the SDGs can be achieved in every major region of the world. TWI2050 is a new initiative designed to fill this gap. The project is a partnership between IIASA, the Earth Institute of Columbia University, the UN Sustainable Development Solutions Network, and the Stockholm Resilience Center at Stockholm University. The project will seek to develop a robust understanding of how modern technologies can support and underpin sustainable development pathways.

TWI2050 consortium will act as a scientific partner for the implementation of the SDGs, playing a similar role to that of the Intergovernmental Panel on Climate Change (IPCC) in the implementation of the UN Framework Convention on Climate Change. However, unlike the IPCC, TWI2050 will be non-governmental. It will provide politically neutral, objective, independent scientific information to support all levels of decision makers charged with the implementation of the SDGs. Importantly global and regional economic and financial institutions (e.g., World Bank, International Monetary Fund, regional development banks) will be integral partners in TWI2050 consortium, thus ensuring scientifically robust economic and investment advice to national governments.

TWI2050 will (i) map out the business-as-usual (BAU) pathway highlighting implications for economic wellbeing, social inclusion, and environmental sustainability at the global scale and in key regions; and (ii) chart an integrated sustainable development pathway to understand the operational implications of achieving inclusive economic and social development goals within planetary boundaries.

Both pathways will explore synergies and trade-offs across all dimensions of sustainable development. The work will address questions such as: How deep does the sustainability transformation need to be in order to meet hunger, poverty, energy, and growth goals while also meeting environmental goals? What are the synergies and trade-offs? What are costs of pursuing social goals without meeting sustainability goals?

By back-casting from desired development outcomes, as defined by the SDGs, TWI2050 will develop a pathway to sustainable development. This will help the global community understand how the world and major regions can achieve all SDGs, and how progress towards this can be monitored. The project will thereby fill a major gap in understanding by analyzing the options, feasibility, and consequences of socially, economically, and environmentally transitioning to a sustainable development pathway.

Instead of developing a new suite of analytical models, TWI2050 will integrate existing world-class models in key sectors (e.g., energy, food, population, education, macroeconomics, biodiversity, climate, disaster risks). It will combine existing global assessments (e.g., those undertaken by the IPCC)

and national scenarios (e.g., the Deep Decarbonization Pathway Project), with existing models in key sectors and recent advancements in economic modeling and Earth system science. Models that can be used for this work include, for instance, the Global Biosphere Management Model (GLOBIOM), the Global Agro-ecological Zones model system (GAEZ) and the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which can all be used to assess global food policy; for ecosystem changes the Integrated Model to Assess the Global Environment (IMAGE), and for climate and energy the Model for Energy Supply Systems And their General Environmental impact (MESSAGE). This pragmatic approach will allow TWI2050 to compare the BAU and sustainable development pathways for different sectors and at multiple spatial and temporal scales.

This approach differs from the more standard method of putting all elements of sustainable development into a single integrated assessment model (IAM) managed by a single research team. The goal is rather to harness the knowledge of specialized institutions in an integrated framework, but not necessarily in a single integrated mathematical model. Existing IAMs, however impressive, generally fail to encompass the deeper insights of the highly specialized sector models. At the same time, these individual sector models fail to incorporate the general systems interactions built into the IAMs. TWI2050 aims to bridge that divide in a novel and constructive manner, by bringing specialized sector models managed by lead institutions into an integrated framework.

This approach has another long-term advantage: it will strengthen the performance of the key participating institutions, by forcing their modeling efforts to confront the critical parameters and issues arising from other sectors not described in their own models. The International Monetary Fund, for example, runs macroeconomic models but without the benefit of a specific medium-term framework on climate change, which in turn has implications for long-term growth. Food modelers do not necessarily incorporate macroeconomic feedbacks; energy system modelers do not incorporate demographic factors, and so it goes on. The longer-term benefit of TWI2050 will therefore be an enhanced global capacity of leading institutions to engage in complex systems analysis.

Finally, the TWI2050 approach differs from standard IAMs by asking a goal-based question. Rather than examining various future scenarios, the project will focus on describing a potential sustainable development trajectory, that is, one in which economic development and inclusive growth proceeds in all regions of the world, thereby achieving the SDGs while respecting planetary boundaries. This is a normative approach that is not present (even potentially) in much of the world's forecasting work on energy, macroeconomics, demography, and other issues of critical importance. Most models are designed as projections of the BAU trajectory, not as elucidations of how to achieve a sustainable development pathway.

Importantly, the project will examine the interactions among all the SDGs to explore the potential for co-benefits and/or trade-offs of addressing multiple SDGs at the same time. We anticipate that these analyses will provide critical information for policy and investment decisions. Initially these analyses will be conducted at the global and regional scales, but over time will be downscaled to sectoral and national levels to better inform policy making.

The project will engage with key international expert institutions, based on their expertise regarding critical domains of sustainable development, and in particular institutions that house global models, data, and analyses on global futures. The project will build on, and continually iterate, the existing

modeling efforts of partner institutions, combining models, datasets, and economic analyses, with updated assessments of future developments and costs/benefits (e.g., damage functions with rising global mean temperature) to build a better understanding of the consequences of altering planetary processes beyond a safe operating space.

All IIASA research programs will contribute to this initiative.

Integrated Solutions for Water, Energy, and Land (IS-WEL)

The UN Sustainable Development Goals (SDGs) specify water, energy, and land as critical resources for enabling human development. In a future where economic development, population growth, urbanization, and changing diet and lifestyle preferences are expected to increase the demands for these resources, it will be crucial to develop coherent strategies for managing them sustainably. Furthermore, climate change is projected to alter the global distribution and quality of these resources with potential consequences for localized resource scarcity and supply challenges. Given these projections, major concerns have emerged regarding whether resource constraints will hamper future human development and how water, energy, and land resources can be managed to enable sustainable development that remains within planetary boundaries.

Evaluating and identifying solutions for the sustainable management of these resources requires an integrated approach as the supply systems for water, energy, and land-based services (e.g., food, forest products, bioenergy, and other ecosystem services) are tightly coupled and interdependent. As an example, the expansion of irrigated land as a solution for increasing food and bioenergy production will have implications for both water and energy supply systems. In addition, it is critical that assessment tools have the capability to provide decision makers with consistent insights across multiple spatial scales. This is because the biophysical factors determining resource availability are generally local (e.g., precipitation and land cover), while solutions may be local, regional, or even global in scale (e.g., international trade and regional cooperation as a mechanism for mitigating localized resource scarcity).

The IS-WEL partnership will leverage the scientific expertise of IIASA and the development expertise of Global Environment Facility and the UN Industrial Development Organisation to develop a consistent, integrated assessment framework for informing investments and decision-making with respect to the sustainable development of water, energy, and land resources at urban, regional, and global scales. This next-generation framework will be used to identify synergies and trade-offs among sectors; to highlight robust planning strategies for local and regional stakeholders; to provide policy recommendations for national and global decision-makers; and to inform targeted and effective investments by development agencies.

The partnership will consist of regional and global assessment phases. During the regional phase, the integrated assessment tool will be developed and tested in two regional case studies in Africa and Asia. This analysis will integrate spatially-explicit water, energy, and land-use models to identify regional challenges regarding the sustainable provision of water, energy, and land-based services and solutions for ensuring sustainable development. Case study regions will be selected to capture the challenges associated with the major drivers of global change, including population growth, urbanization, economic development, and climate change. In each region, stakeholders will be

engaged to build local capacity and to ensure that the relevant policy, development and resource questions are addressed. As such, the initiative will have an important capacity building component.

In the global phase, the regional analysis will be scaled up and linked with existing global integrated assessment frameworks to include the implications of the water-energy-land nexus for global challenges (e.g., climate change) and to evaluate the role of global solutions (e.g., new technologies and practices) for addressing regional food, water, and energy security concerns. The global analysis will also be used to identify vulnerability hotspots where sustainable development may face resource constraints and where future case studies should be focused. In both phases, key insights will be communicated to stakeholders, development agencies, government institutions, and the scientific community with the aim of informing decisions and investments to ensure that humanity remains on a sustainable development pathway.

Currently contributing IIASA research programs: ENE, ESM, TNT, WAT.

Futures Initiatives

Established in 2014, the IIASA futures initiatives are cross-sectoral and/or regionally focused projects designed to explore plausible futures for a number of the world's rapidly transitioning regions or resources. The current four internally funded futures initiatives will continue at least into the first half of the five-year research period at the current level of activity and funding. Future expansion will depend on the success of the initial build-up phase of each initiative and the ability to attract significant external funding support. It should be noted that at this time each of these initiatives are at different stages of development.

Arctic Futures

Objective and uniqueness

The complexity of the dynamic global system poses significant societal, research, policy, and governance challenges for the fragile Arctic. Global social, economic, and technological changes all contribute to transformations in the Arctic climate, industries, environment, and societies. Conversely, changes in the Arctic environment have an effect on the global climate system and therefore also affect other regions.

Research efforts on the Arctic are multiple, but fragmented. There is a need for a holistic, integrative assessment of plausible futures for the Arctic, cutting across different disciplines and individual countries' strategic interests. The Arctic Futures Initiative (AFI) works collaboratively with key Arctic institutions and organizations to bring together affiliated stakeholders to support an integrated, "end to end" science to decision-making framework that involves the 23 IIASA National Member Organizations, which include five Arctic nations and six observer nations of the Arctic Council.

The objective of the AFI is to create a collaborative, science-based process by applying systems analysis to better understand plausible futures and inform decision making within and beyond a rapidly changing Arctic. The specific goals of the AFI are to:

- Co-design and prioritize an integrated, participatory science agenda by engaging the research, policy, business, and indigenous communities;

- Systematically formulate a range of plausible development pathways in the context of a rapidly changing Arctic;
- Assess the consequences of future pathway decisions on social, economic, and environmental systems across the Arctic and the broader Earth system;
- Sustain the AFI science-based process using adaptive management practices to improve and refine decision support.

The AFI seeks to add unique value to current Arctic research efforts, by providing:

- A collaborative environment for developing decision-relevant and co-designed research with Arctic stakeholder communities;
- A transparent, participatory process for scenario and model development for plausible Arctic futures;
- A systems-based methodology and tools to analyze multi-scale, multi-sector, and interdisciplinary issues in the Arctic.

The AFI builds on the capacity of IIASA as an independent, international, scientific institute to bring together stakeholder groups to define Arctic research questions. IIASA has state-of-the-art expertise in complex systems analysis, scenarios, and modeling, as well as integrative and participatory techniques that can contribute to decision-relevant research to be applied in the broader Arctic context.

Key research questions and outlook

The specific research questions to be addressed by the AFI are currently being developed and refined with Arctic stakeholders. In this context, there are several overarching questions that the AFI seeks to answer. What are the plausible futures for the Arctic and pathways to those futures? What information do decision makers need to make those futures sustainable? How can the numerous, potentially conflicting Arctic interests—socioeconomic, environmental, and cultural—be reconciled as the Arctic system changes?

The AFI, currently in its planning phase, aims to be a long-term, international, collaborative, and integrative research project to examine the plausible futures of the Arctic through engagement with Arctic science, policy, and business communities and their diverse array of stakeholders, as well as indigenous groups. For example, the AFI has started collaboration with the Arctic Council by engaging US chairmanship representatives, senior Arctic officials, working groups, and specific projects, such as Adaptation Actions for a Changing Arctic and the Arctic Resilience Report. The AFI is also working closely with the Arctic Economic Council, which facilitates Arctic business-to-business activities and responsible economic development.

The outlook for the next 2-3 years for the AFI is:

- *Planning Phase* (until mid-2016): Plan workshops; draft a strategic plan; establish a governance structure; and explore optimal connections with ongoing IIASA research;
- *Development Phase* (mid-2016 to beginning of 2017): Engage policy, business, and research stakeholders; co-design research, implementation, and adaptive management plans; and develop a funding strategy;

- *Launch Phase* (2017 onwards): Build on devised plans for research, implementation, and adaptive management.

Currently contributing IIASA research programs: ASA, AIR, ENE, EEP, ESM, RISK, POP, WAT.

Futures of Economic Integration within the wider European and Eurasian Space

Objective and uniqueness

This IIASA Futures Initiative deals with the complex issues of economic cooperation between countries of the Eurasian continent.

During the last few decades, international economic policies have been turning towards regional integration in various new and diverse forms. Not only has the number of regional integration arrangements increased but, even more strikingly, their scope and depth have expanded in a remarkable manner. The systemic development of the EU internally, coupled with its successive enlargements and more recent neighborhood policy, has been the most ambitious integration process so far. The establishment of the Customs Union of Russia, Belarus, and Kazakhstan in 2010, and its subsequent evolution into the Eurasian Economic Union (EAEU) with five member states in 2015, represents a major new example of regional economic integration in northern Eurasia. The interaction between the two integration processes creates opportunities for better economic development in the countries involved, but it also poses many challenges for ensuring mutual compatibility, fairness, and sharing the associated costs and benefits of closer cooperation and integration.

This international and interdisciplinary Futures Initiative aims to discuss and analyze critical issues of economic cooperation between the EU, EAEU, and their neighbors, extending also, where relevant, to the USA as well as the key Asian players, such as China, India, Japan, and Korea.

Key research questions and outlook

The pilot three-year (2014-2016) phase of the initiative consists of a series of scoping workshops at which specific aspects of integration—notably, trade policy, non-tariff barriers, technical regulation, energy, transport and infrastructure, education, labor market and migration, and investment climate—are discussed by scientists and stakeholders representing all interested regions.

Deliberations of the pilot phase will provide the foundation for the research phase of the project.

The research is expected to focus on two dimensions:

- *Theory: Integration, disintegration, and economic cooperation*. This component will address the following research questions: What is the future of regional integration? What are the consequences of rising inter-regionalism? What are the ways to raise efficiency of regional organization and narrow implementation gaps? What is the impact of integration and disintegration on economic development and welfare? The goal of this component is to carry out a systematic, theoretical assessment of different options for economic integration, disintegration, and various modes of economic cooperation, primarily at the regional level.

- *Policy: Perspectives and roadmaps of deeper cooperation between the EU and the EAEU*. Based on the above theoretical findings, this policy-oriented research component will develop a set of possible options for closer cooperation between the EU and the EAEU, and supplement them with draft sectorial roadmaps.

Currently contributing IIASA research programs: ASA, ENE, RISK, POP.

Tropical Futures

Objective and uniqueness

The contribution of the tropical region is crucial to the global challenges today. The rainforests of the Amazon, the Congo, and Southeast Asia are home to the greatest biodiversity on the planet, and serve as a climate regulator for the entire Earth system, absorbing millions of tons of CO_2 a year. The Tropical Futures Initiative (TFI) aims to provide scientific and strategic analysis to policymakers in the tropical region to better understand the dynamics of transitions and their main driving forces, enabling factors, barriers, as well as their consequences for the social, economic, and environmental dimensions of human wellbeing and sustainability. TFI puts emphasis on creating a bridge between science and policy through joint capacity-building activities that will eventually lead to practical scientific decision support and joint research activities in the area.

TFI combines strengths of various IIASA programs to collaborate with governments and research institutes in tropical regions. Since its launch in 2014, TFI has been working very closely with government institutions in Indonesia as well as various research institutes to adapt and apply IIASA models that are relevant for the region. The Global Biosphere Management Model (GLOBIOM) is used as an entry point in supporting policymakers to conduct integrated assessments of land use, integrating the agricultural, bio-energy, and forestry sectors. The work done in Indonesia will be built on the Brazilian template developed through a four-year REDD-Policy Assessment Center initiative in Brazil and the Congo Basin, funded by the German Federal Environment Ministry's International Climate Initiative.

Because a holistic perspective is required for the assessment of transitions in the area, this work extends to sectors beyond forestry. In 2015, collaboration with the IIASA Energy Program began, with the objective of linking GLOBIOM with the Model for Energy Supply Systems And their General Environmental impact (MESSAGE) at the macro level and with the BeWhere model for techno-economic analysis. Such linkage will be built through direct application in relevant government institutions to assist policymakers in dealing with daily challenges. IIASA will host research schools to build indigenous quantitative assessment capacity for government and local scientific representatives. These efforts will result in the establishment of a decision-support system that will enable evaluation and improvement of existing plans and implementation of new policies. More importantly, this work will open up new ground for further scientific assessment, yielding results that are valuable beyond the pilot countries and the tropical region.

Key research questions and outlook

TFI's research strategy for 2015-2020 will focus on land-use policy modeling through GLOBIOM (with the support of other Ecosystems Services and Management Program models such as the Environmental Policy Integrated Model and the Global Forest Model (G4M)), macro-level energy

systems modeling using the MESSAGE model, and techno-economic analysis using the BeWhere model.

Modeling for land-use policy impact assessment. The activity will start with the development of a land-use, driver, and forest resource assessment. GLOBIOM will trace biophysical accounts (e.g., forest carbon stock, soil carbon, greenhouse gases, erosion, and nutrient flows), economic accounts (e.g., total market balances including imports and exports, food prices, and land values) and possibly socioeconomic accounts (e.g., malnutrition, poverty, rural employment).

Updated forest production possibilities and their associated costs and carbon consequences can be delivered by G4M, although this may be substituted by an improved indigenous model. The model (including species and age cohorts) will be adapted to simulate forest (carbon) dynamics in Brazil and Indonesia.

A significant part of the work, particularly in ensuring successful capacity building and joint research collaboration, is quality management. Quality management includes the processing, comparison, harmonization, standardization, and validation of input data. In addition, interoperability management and data registration with GEO and the national data portals; model documentation and version control; and consistency checks of model outputs are needed. Furthermore, it is planned that in the operational phase, Brazil and Indonesia will be able to run their own versions of their (sub) national model(s). The state of the final model clusters will be documented in a technical model manual by the country teams.

Energy systems long-term impact assessment and short-term decision-making support. Policymakers often need to make decisions on a detailed and technical level without losing sight of the bigger picture. Energy system models are used at the macro level to project optimized scenarios to cope with energy demand. These provide top-down insight for policymakers to determine long-term information at the more aggregated level of energy systems. In contrast, daily decision-making questions deal with case-specific issues where direct correlation with the energy system is substantially less visible.

An effective decision support system requires in-house capacity for analysis at the energy-system level with clear framework for compatibility with sub-system analysis and even case-specific studies. The combination of a macro-level energy model, such as MESSAGE, and a techno-economic model, such as BeWhere, creates a decision-analytical framework to explore the role of the energy sector in addressing policy trade-offs between different sustainable development objectives. TFI focuses on capacity building and joint research activity for the regional adaptation of MESSAGE and BeWhere models. In close collaboration with the Ministry of Energy and Mineral Resources in Indonesia, IIASA will examine the following potential issues: long-term energy policy, energy technology projection, energy access, localized energy supply optimization, bioenergy versus fossil fuels, and mineral processing optimization.

Currently contributing IIASA research programs: ENE, ESM, POP, WAT.

Water Futures and Solutions

Objective and uniqueness

The Water Futures and Solutions (WFaS) initiative is a cross-sector, collaborative, global initiative which applies systems analysis to help identify portfolios of water-related policies and management practices that work together consistently across scales and sectors to improve human wellbeing through water security. A stakeholder informed, scenario-based assessment of water resources and demand, employing multi-model ensembles of state-of-the-art socioeconomic and hydrological models, test the feasibility, sustainability and robustness of options that can be implemented across a range of possible futures. Exploratory case studies zoom in on particular issues and regions to investigate values and goals, possible pathways and effective options in those regions. These studies are also used to develop and enhance new methodologies for cross-scale and cross-sector analysis of particular processes. Knowledge-sharing networks share policy, management, and technical solutions that have been effective in the bio-physical and socioeconomic contexts to which they have been applied, so they can be assessed for application in other regions.

Key research questions and outlook

Knowledge hub and global network for systems analysis approaches to the global water challenge. Broad participation of the water community, and those of related sectors, is essential for advancing knowledge and science, and for providing consistent analyses and messages to decision makers across sectors and scales of management. This will foster consistent, comprehensive, and effective implementation of development projects in water, energy, and food. More than 40 institutions are already partners of WFaS, which will establish a water knowledge hub at IIASA, convening scientific and stakeholder coalitions across sectors and disciplines. In coming years, knowledge sharing will be enhanced through the development of online databases, tools to help communicate and visualize trade-offs and synergies among policy options, and online platforms for information sharing on options and the conditions under which they are most effective.

Water Futures—comprehensive, cross-sector, stakeholder-informed assessments of present and future water requirements and availability. WFaS extends and develops innovative methods for integrated analysis, while leading a global, state-of-the-art, stakeholder-informed assessment of water supply and demand balances. This assessment provides future scenarios that are consistent with those developed in global assessments for other disciplines and sectors, such as the Intergovernmental Panel on Climate Change's Shared Socioeconomic Pathways. WFaS has already developed the first set of integrated scenarios, quantified with multiple-model ensembles. These will continue to be adjusted with stakeholders and will be further enhanced with innovations improving the nexus model integration, water demand estimations, and better incorporating groundwater, water quality, and institutional change.

Uncovering water solutions—trade-offs and options across the food, water, and energy nexus. While the early focus of WFaS has been on establishing coalitions, building scenarios, and assessing water futures, the focus will shift in coming years to the assessment of options across the climate/energy/environment/food/water nexus. This analysis will include: (i) identifying and testing measures for improving water supply, elaborating demand-side intervention options, and evaluating policy, institutional, and behavioral changes for improving water management and enhancing water services and security; (ii) uncovering water solutions at multiple scales by applying a multi-disciplinary

systems analysis framework and tools to identify and anticipate water gaps and risks and to assess and evaluate portfolios of water management and development options for their robustness, sustainability, coherence, and synergies across sectors and management scales; and (iii) providing and maintaining water-related online decision support tools and knowledge-sharing networks.

Currently contributing IIASA research programs: ENE, ESM, WAT.

Emerging and possible developments

In addition to the initiatives described above, IIASA researchers, together with relevant representatives in member countries, are discussing the feasibility of additional activities including in regions such as the Middle East, southern Africa, Southeast Asia/Pacific, and Japan, China, and the Republic of Korea.

Cross-cutting research

Cross-cutting research at IIASA is implemented through a number of internally funded projects. These primarily methodology-focused projects represent unique and unaddressed research challenges that require integrated and interdisciplinary expertise and focus. These projects address not only cutting-edge research questions, but, by drawing upon expertise from across the IIASA research programs, also promote greater collaboration and integration across the institute. IIASA currently has three such projects, initiated in 2014, that will continue at least into the first half of the this five-year research period at the current level of funding.

Equitable governance of common goods

The imperative to protect common goods unites the majority of challenges that IIASA addresses. Protective measures—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 are thus readily jeopardized by selfish agents—be they citizens, companies, cities, or countries—resulting in social dilemmas that follow the 'tragedy of the commons.' Salient examples related to common goods and the possibility of a tragedy of the commons include not only climate change and natural resources, but also clean air, civil security, social welfare, ecosystem services, land use, prudent urbanization, natural-disaster protection, restrained demography, and the functioning of the internet.

The universal nature of common problems suggests the potential for common solutions. These may take the form of norms or treaties coming from the bottom up, or of regulations or incentives imposed from the top down. Bottom-up governance is often not only remarkably efficient, but also tends to be perceived by stakeholders as equitable and fair. Such governance, however, is typically successful only when the number of stakeholders is sufficiently small, so that social agreements can be struck and enforced. In contrast, top-down governance has been marred by a history of fiascoes. It is bound to fail when based on insufficient analyses of underlying systems dynamics, when stakeholder interests are misconstrued, when side effects and loopholes of incentives are overlooked, and when processes of stakeholder reconciliation malfunction. Rules that go against established social norms can also result in failure, as can governance structures or enforcement mechanisms that are inadequate. What unites bottom-up and top-down governance are social institutions that aim to facilitate the equitable

governance of challenged common good. This cross-cutting project examines how best to design such institutions, taking into account realistic complexities of human behavior.

Achieving this requires the confines of current disciplinary approaches to be overcome. This project draws on advances in game theory, cultural theory, behavioral economics, choice theory, collective phenomena, and agent-based modeling. It emphasizes the role of institutions (instead of focusing on pairwise interactions among stakeholders); acknowledges bounded rationality (instead of relying on the *Homo oeconomicus* assumption); accounts for a plurality of values and preferences among stakeholders (instead of glossing over such social diversity); and considers realistic system dynamics (instead of ignoring lag effects, history dependence, non-equilibrium processes, and tipping points).

The research is pursued through four interconnected approaches. First, selected case studies are reviewed to identify key elements of how social dilemmas play out in the real world. Second, experimental games of increasing complexity are designed and carried out through computerized interfaces to gain insights into the relative importance of these elements and their interactions. Third, agent-based models are constructed to capture the insights from these experiments. Fourth, stylized models are devised to show how behavioral patterns observed in real-world, common-good governance can be understood from minimalistic principles.

Currently contributing IIASA research programs: EEP, RISK.

Socioeconomic heterogeneity in model applications

The cross-cutting project Socioeconomic Heterogeneity in Model Applications (SCHEMA), will study how better accounting for socioeconomic heterogeneity in integrated assessments can improve both the prediction of global environmental change and the impacts of related policies on human wellbeing. The project is a collective effort of four IIASA programs with the aim of generating a common layer of socioeconomic inputs that will feed into at least three global models (Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), Global Biosphere Management Model (GLOBIOM), and Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model), thereby enabling more detailed representations of household and transport energy demand, food demand, and exposure to air pollution. The novelty of the project lies in the depth of consumption driver representation and their harmonized application to a range of integrated assessment models, which will ultimately enable a unified and self-consistent accounting of human wellbeing in IIASA modeling.

During the first year (2014-15) the focus of the project was on identifying and producing preliminary projections for key dimensions of socioeconomic heterogeneity (e.g., income distribution and urbanization) and developing methods to incorporate these into the three IIASA models. In the coming years these projections will be refined and extended to some secondary drivers of change such as food and energy demand, followed by research into implications for scenario development and policy impacts. This includes analyzing the changes introduced by socioeconomic heterogeneity to main model predictions and the distributional impacts of various environmental policies on households, through their effect on food and energy prices, and the health impacts of energy-related air pollution.

Currently contributing IIASA research programs: AIR, ENE, ESM, POP.

Systemic risk and network dynamics

Systemic risk describes the likelihood of cascading failures in networks. It can arise in a broad range of disparate systems such as power grids, ecosystems, supply chains, financial networks, disease dynamics, and transportation networks. This project aims to produce a general framework for analyzing systemic risk and to demonstrate the framework's utility for assessing and mitigating the risk of cascading failures in three focal areas: ecological systems, financial systems, and the global disaster-insurance and humanitarian-aid systems.

The unprecedented spread of the 2007-2010 financial crisis that has rippled through the world's developed economies has highlighted the potential for failures to propagate between institutions in complex networks of interdependencies. Cascading failures can be sparked by even very small deviations from business-as-usual functioning modes, resulting in non-smooth transitions to unwanted paths. As the negative consequences of cascading failures can be profound and far-reaching, especially in today's interconnected world, the desire to understand, assess, and mitigate systemic risk has mounted in recent years. This cross-cutting project aims to tackle these challenges.

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 aims to develop (i) cross-cutting measures of systemic risk, (ii) prognostic tools for assessing the likelihood and extent of cascading collapses under uncertainty, (iii) methods for reducing systemic risk through network design and control, and (iv) techniques for guiding network dynamics back to business-as-usual functioning after the onset of a cascading failure.

IIASA is uniquely positioned to undertake this research, with in-house expertise in key areas including network theory (Advanced Systems Analysis Program (ASA) and Evolution and Ecology Program (EEP)), risk analysis (Risk and Resilience Program (RISK)), adaptive dynamics (EEP), control theory (ASA), and game theory (ASA and EEP). To ensure that the expected advances are informed by applied needs, the research will be firmly rooted in the three aforementioned focal areas, thereby drawing on research fields in which the participating programs have extensive experience. In particular, the project is currently developing focus, respectively, on systemic risks in ecosystems triggered by species loss and on systemic risks in financial-economic systems triggered by natural hazards. On this basis, the project will develop cross-cutting concepts and tools, and demonstrate how these can aid in the management of systems and inform mitigation policies. To maximize the likelihood that the anticipated advances will be useful for practitioners, who typically must operate in an environment of uncertainty, the performance of the developed methods will be tested under conditions when the network's state cannot be reliably observed, or specifics about the network's dynamics are unknown.

Currently contributing IIASA research programs: ASA, EEP, RISK.

New cross-cutting projects

Given the success of the initial round of cross-cutting projects, both in generating new science and increasing collaboration across research programs, IIASA will significantly increase internal funding to additional cross-cutting projects over the next five years. Following extensive discussions across research programs three new institution-wide integrated projects will begin in 2016. These are still very much in the scoping phase and will be further developed over the first half of 2016.

Nexus++

The proposed overarching objective of the Nexus++ project is to develop new methods and to integrate existing tools across the institute in order to study "nexus-solutions" for sustainable, social and economic development within safe environmental boundaries. This requires a holistic and integrated analysis of transformational processes, their drivers and barriers, as well as the connections between multiple societal objectives. Importantly, the project aims to integrate both natural and social dimensions of sustainability.

Achieving the aims of the project goes far beyond earlier assessments, integrating the recently adopted UN Sustainable Development Goals (SDGs) into traditionally environmentally focused assessments of the transformation. A major challenge of the project is to appropriately account for the multiple dimensions of economic, social, and environmental sustainability. In order to address the complex interactions and the nexus between the multiple SDGs, a two-pronged approach, including top-down and bottom-up activities across the programs, is suggested:

1. From a top-down perspective, new concepts and methods will be developed to help operationalize and to measure human wellbeing (as an aggregated measure for the degree of sustainability). The top-down framing aims at providing an organizing principle for analysis across different nexus sectors and their contribution to human wellbeing (e.g., contributions of agriculture, forests, energy, water, natural ecosystems, biodiversity, related health challenges, poverty eradication, etc.,).
2. In addition to the top-down framing, the bottom-up activities across programs will focus on the development of a next-generation IIASA integrated modeling framework. The framework would extend and link existing IIASA models in order to study the nexus between different SDGs. To effectively address many of the SDGs, whether at the national or international level, it is important to take an integrated and holistic perspective, accounting for probability and risk, so that linkages between SDGs can be fully recognized in decision making. The ambition of the bottom-up model development is to go beyond state-of-the-art (climate mitigation or environmental transition) scenarios and instead explore as yet underdeveloped pathways that ensure the achievement of a wide range of sustainable development objectives.

Enlarging current capabilities in systems analysis at IIASA, research in this cross-cutting project will be complemented by the development of new concepts and methods to interface and integrate models. It will also: (i) link complex and reduced-form models; (ii) define robust and "sufficiently optimal" solutions; (iii) describe and reconcile diverging interests among stakeholder groups; (iv) anticipate and guide co-evolutionary dynamics in complex adaptive socio-bio-economic systems; (v) devise and apply principles of adaptive management for adjusting current policy interventions in pursuit of long-term objectives; (vi) understand and predict bounded rationality in human decision making.

Current approaches to reflect human decisions and preferences outline the plausible range of human decisions along multiple "story-lines" (e.g., the shared socioeconomic pathways), which are dealt with as exogenous drivers for the physical-techno-economic models.

To incorporate human decisions into the next generation of models of global transformational pathways, IIASA programs will cooperate in the Nexus++ project to:

- Develop a broader understanding of the human driving forces of global change, and how they are influenced by a wide range of factors;
- Account for plural views on human wellbeing and sustainability in identifying and comparing aggregate measures;
- Understand how the social dynamics associated with cultural diversity influence support for policy interventions;
- Explore how policy decisions that influence global change will feed back on aspects that are considered important by the society (including the SDGs);
- Assess how these feedbacks will influence human decisions about transformational strategies; and
- Integrate these mechanisms into the next generation of physical-techno-economic models.

Inter alia, the work will take full account of the social heterogeneities that influences the decisions on transformational change and the perceptions of it.

All IIASA research programs are contributing to this initiative.

The new climate community scenario framework

Over recent years, IIASA researchers have been instrumental in establishing the so-called "parallel community process," which aims to develop climate scenarios to facilitate an integrated analysis of climate change impacts, adaptation, and mitigation. In the initial phase the communities collaborated to develop the Representative Concentration Pathways (RCPs), which are hosted at IIASA and form the backbone of the climate projections assessed by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). In the second phase of the parallel process the socioeconomic dimension of the new community scenarios will be elaborated. The primary goal of this phase, which is to be completed soon, is the development of the Shared Socioeconomic Pathways (SSPs). This framework is built around a matrix that combines climate forcing (as represented by the RCPs) and socioeconomic conditions (as represented by the SSPs). Together, these two axes will provide the basis for the assessment of future mitigation, adaptation, and residual climate damages.

To date, IIASA has played a central role in the design of the overall process. The institute has provided scientific input by developing one of the five RCPs and is currently working on the development of the SSPs; has spearheaded organizing the IPCC Working Group III community under an umbrella organization (the Integrated Assessment Modeling Consortium); and has been charged by the community and the IPCC to host related community databases for both the RCPs and the SSPs.

The SSPs will provide, over the coming years, a central reference for integrated climate change research and a common basis for a set of joint assumptions across various types of analysis (from mitigation to adaptation and the physical response of the system). An important first step toward the

integration of IIASA research on the human dimension of global change with socioeconomic and technical analysis of energy, land-use, and ecosystem changes has been already achieved. Research in this area over the coming years will comprise collaboration across a host of IIASA programs in the development of the next generation of climate scenarios. This will include the development of spatially explicit information on emissions and land-use changes for the community flagship project of the climate science community (Coupled Model Intercomparison Project Phase 6) as well as dedicated work for continuously extending the RCP-SSP framework for climate impacts, vulnerability, adaptation, and mitigation.

Currently contributing IIASA research programs: AIR, ENE, ESM, RISK, POP, WAT.

Dynamic vegetation models: the next generation

Twenty-five years after they were conceived at IIASA, Dynamic Global Vegetation Models (DGVMs) are now indispensable for understanding the biosphere. While their versatility is increasing as new processes and variables are added, their accuracy suffers from the accumulation of uncertainty, especially in the absence of overarching principles controlling their concerted behavior. This initiative 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 therefore can vastly reduce the number of uncertain parameters in ecosystem models, it has rarely been applied to DGVMs. Recent research developments have shown that optimization- and trait-based models of gross primary production can be both simpler and more accurate than current models based on functional types, and that observed vegetation structures and distributions of plant traits can be predicted with new eco-evolutionary models.

Using these innovations as a springboard, this project aims to operationalize these concepts in an international, multidisciplinary, IIASA-coordinated working group, led by experts in the following key areas: eco-evolutionary theory, systems analysis, vegetation modeling, and DGVM applications. Complemented by matching in-house research, network-based research efforts will unfold through a series of IIASA workshops and are intended to culminate in an international IIASA conference.

Currently contributing IIASA research programs: ASA, EEP, ESM.

Links between integrated, cross-cutting, and core research at IIASA

Large-scale integrated projects and cross-cutting activities are a new feature of this research plan, and are increasingly becoming a major focus of the IIASA research portfolio. In 2015, IIASA invested approximately 20% of the institute's internal funds to these projects, with this proportion being projected to increase to approximately 40% over the next five years. These projects build on the institute's strengths by bringing together the necessary core expertise from across all IIASA research programs to build truly integrated, interdisciplinary teams to address the research objectives (Figure 4). It must be emphasized that the research undertaken within these integrated and cross-cutting activities is conducted as coordinated collaborative projects within and across the IIASA research programs and external networks and not as independent operating units.

Figure 4. Matrix showing how each IIASA research program currently contributes to integrated and crosscutting research activities at IIASA (does not exclude future contributions).

Activity	Research Program								
	ASA	AIR	ESM	ENE	EEP	RISK	TNT	WAT	POP
Cross-cutting research									
Nexus++	■	■	■	■	■	■	■	■	■
Equitable governance					■	■			
Socioecon. heterogeneity		■	■	■					■
Systemic risk & network dyn.	■				■	■			
Climate community scenarios		■	■	■		■		■	■
Dynamic vegetation models	■		■		■				
Large-scale integrated projects supporting global transformations									
Arctic Futures	■	■	■	■	■	■		■	■
Eurasian Econ. Integration	■			■		■			■
Tropical Futures			■	■				■	■
Water Futures			■	■				■	
TWI2050	■	■	■	■	■	■	■	■	■
IS-WEL			■	■			■	■	

Core research

Currently, nine research programs carry out research at IIASA into the dynamics of global change across broad research themes. In addition to contributing to large-scale integrated projects and cross-cutting initiatives (Figure 4), each research program is responsible for undertaking research and maintaining and developing core research competencies across their areas of expertise. It must be stressed that the IIASA research programs are not discipline-based, but are themselves interdisciplinary and house a diversity of scientific expertise, across the natural (e.g., biology, chemistry), physical (e.g., physics, mathematics, engineering), and social sciences (e.g., economics, demography, geography) that together focus on a particular research theme.

For each research program, a summary of the program's unique niche, measurable objectives for the next five years, and expected impact is provided. This is followed by a more detailed overview of the program, its strengths and uniqueness within the overall IIASA context, and the research outlook for the next five years, including both continuing and new research activities.

Advanced Systems Analysis Program (ASA)

NICHE: Increasing recognition of the systems nature of global challenges, and unprecedented new streams of data from scientific, governmental, and commercial sources, requires new and improved systems analysis approaches. Working in close cooperation with the applied research programs at IIASA, ASA is uniquely positioned to focus the latest developments in applied mathematics and modeling to expedite the transfer of application to methods and methods to application to either solve problems that cannot be addressed by existing tools or solve problems more efficiently.

OBJECTIVES

- Improve the practice of transferring methods at IIASA through co-design of research questions and methodological approaches in collaboration with stakeholders and policymakers.
- Enhance ASA's scientific leadership at the interface between systems analysis methodology and applications.
- Improve methods and techniques used in decision-support models to deal with long-term non-linear dynamics, uncertainty, multiple agents, and multiple objectives.
- Develop and implement new analytic approaches to the resilience of economic, financial, and ecological networked systems.
- Advance approaches, practices, and rigor of qualitative research that involves stakeholders and decision makers, and transfers the analytic results into the decision-making processes.
- Showcase the utility of advanced systems analysis approaches and techniques in important, policy-relevant case-studies. For example, economic growth or natural resource management models addressing sustainability

EXPECTED IMPACT: The scientific impact of ASA is three-fold. More sophisticated methods can offer insights into previously intractable problems, helping applied scientists understand options for solving complex, real-world problems cutting across social, economic, and environmental dimensions. Conversely, ASA's collaboration with the applied research programs can bring new problems to the attention of the mathematical community, triggering spill-over methodological developments. Development of the methods and approaches to incorporate stakeholders, including policymakers, will support the partnership between science and policy.

Objective and rationale

An integral part of the IIASA mission is the development of new and more sophisticated systems analysis methods. Responding to this methodological part of the IIASA mandate, ASA aims to produce, practice, and prototype—in an integrated and interdisciplinary fashion—novel, systems analysis approaches, methods, and tools to solve problems that cannot be addressed by existing tools or to solve problems more efficiently.

Methodological research has been carried out at IIASA since its foundation. ASA has inherited good traditions from previous generations of methodologically oriented IIASA groups and builds on the strengths of mathematical schools from IIASA member countries.

ASA initiates and carries out collaborative, problem-oriented, small-scale exploratory research projects. It maintains and develops a large network of researchers, experts, and decision makers, who are mobilized for particular projects when needed.

Many ASA projects focus on particular systems of the coupled human-environment complex and aim to (a) reveal tendencies of its dynamics, understand the role of drivers and feedbacks, and evaluate possible impacts (descriptive analysis) and/or (b) suggest solutions aiming at achieving certain objectives (normative and prescriptive analysis). In its drive to experiment with new methods and applications, ASA often employs "stylized" models—models which rely on only a few equations and parameters; these do not aim to capture the details, but focus on key drivers, impacts, and relations to understand the central feedbacks and the role of critical parameters. Applications are chosen in compliance with the overall IIASA research agenda, where breakthroughs in terms of fulfillment of the ASA strategy are expected.

Main strengths and uniqueness

ASA works at the interface between systems analysis methodology and applications. Regular formal and informal interactions of ASA researchers with their applied colleagues across the institute lead to on-going cross-fertilization. Through this rather unique arrangement, ASA researchers are able to efficiently learn about the needs and challenges of applied research, while offering novel methods and approaches to better solve problems that other programs and researchers are dealing with.

The exploratory character of research is key to the ASA mission. In addition, two key strengths underlying the successful implementation of ASA strategy are: the consolidation of the wide experience of ASA researchers in various fields of applied mathematics and applications, and the program's broad international and interdisciplinary network.

Key research questions and outlook

Systems analysis treats the coupled human-environment complex as a hierarchical system of interacting (sub-)systems. Each research question involves one of three possible levels of analysis:

- *Particular (sub-)system* focusing on decisions taken for a (sub-)system within a larger system.
- *Interactions between (sub-)systems* focusing on (dynamic) connectivity between systems.
- *System of (sub-)systems* focusing on the state and dynamics of the entire complex system.

Correspondingly, ASA research is organized around three mutually complementary and cross-fertilizing research domains.

The **optimal behavior of systems** domain focuses on how making decisions that govern systems' behavior can be formalized in models, notably, under uncertainty and risk, and what consequences different decisions yield. Understanding dynamics of economic growth, fueled by the exploitation of natural resources, as well as the multi-dimensional impacts in the highly interconnected and volatile

modern world are the keys for designing solutions aimed at increasing human wellbeing, facilitating an efficient and fair use of natural resources, while remaining within planetary boundaries. In practice, science offers policymakers tools in which decisions are formalized and their outcomes are evaluated, taking into consideration various uncertainties. These tools often assume that economic agents make decisions on allocating resources between competing goals based on maximizing their utility.

Development of economic growth and resource management models, and advancing corresponding methods of optimal control theory and multi-criteria analysis – ASA analyzes the role and mechanism of the drivers of economic growth and the impact of various constraints and decision maker's objectives. For this, the program's researchers develop appropriate analytical and numerical optimization methods. In 2016-2020 ASA will continue to develop methodological advances in the theory of optimal control with the ambition to further generalize the methodology based on the "maximum principle" for problems with infinite time horizons. This will provide a powerful tool for macroeconomists to analyze more sophisticated economic growth models at the appropriate level of mathematical rigor. ASA researchers will continue to analyze particular models of economic growth with new drivers and impacts. In particular, models with random shocks and those with heterogeneous agents, also under environmental constraints. This work will yield new insights for policies fostering sustainable economic growth.

Development of multi-sectorial resource management models ("nexus" models) under uncertainty and risk, and advancing corresponding stochastic optimization methods – ASA derives robust solutions to problems with inherent uncertainty, and advances appropriate analytical and numerical methods of stochastic optimization. In 2016-2020 ASA researchers will attempt to develop a comprehensive theory to solve non-stationary spatio-temporal nested stochastic optimization problems. ASA will continue collaborating with the Ecosystems Services and Management Program on including alternative risk aversion options in the Global Biosphere Management Model (GLOBIOM), as well as to develop national/regional case studies (China and Ukraine). Another direction for development will be advancing data harmonization techniques for integrated local-global analysis of spatio-temporal systems.

Development of heterogeneous population models, and advancing corresponding methods of optimal control theory for distributed systems and multi-criteria analysis – ASA analyzes strategies for optimal management of heterogeneous biological resources (e.g., forests) and trade-offs between economic and environmental goals by means of size-structured population models, and develops appropriate analytical and numerical methods to solve these models. In 2016-2020 ASA researchers will continue exploration of such models with a particular focus on quantifying trade-offs between economic and environmental objectives in management.

The **interactions within systems** domain focuses on the role of indirect links and connectivity between individual systems within larger networked systems. It has blossomed in the last few years in line with the active worldwide development of "complexity science" and "network science". Unprecedented interconnectedness between ecosystems, regions, countries, institutions, and individuals in the modern world create opportunities, as well as new burdens and threats. Opportunities arise through a higher diversification of supply options that ensure more sustainable resource availability, while burdens are due to the fact that maintaining a more complex network creates higher overhead and threats emerging from systemic risk, that is, cascading failures in networks. Science is challenged to

provide evidence on what role the system's underlying structure plays in defining its operating efficiency. ASA researchers aim at gaining insights by studying natural and human-made systems, empirically, analytically, and by simulations.

Network analysis of the role of indirect connections in natural and socioeconomic real-life systems – ASA develops methods and case studies, empirically analyzing ecological, economic, energy, financial, and other networked systems. These methods often originate in the natural sciences, and are then transferred to the social sciences. In particular, in 2016-2020 ASA researchers will attempt to establish empirical evidence connecting network analysis-based indicators and historical resilience of corresponding systems, and suggest methodology for deriving policy implications. In order to do so, the program will analyze several case studies based on real historical data.

Modeling network dynamics and evaluating systemic risks in natural and human-made networks – ASA develops modeling frameworks and case studies to analyze cascading failures in networks, investigate the influence of the underlying network structure and agents' behavior on the vulnerability of systems, and elaborate solutions to lessen systemic risks and improve recovery. In 2016-2020, the focus will be on two types of systems—ecological networks and economic-financial networks. This work will be done in collaboration with Evolution and Ecology and Risk and Resilience Programs in the framework of the IIASA Systemic Risk and Network Dynamics cross-cutting project.

Strategic interactions between agents – ASA advances understanding of decentralized decisions in a game-theoretic framework. In 2016-2020 ASA researchers plan to design and implement mathematical tools to understand the structure of competitive and cooperative aspects of interactions. Furthermore, the dynamic responsiveness of agents to these structures will be examined in order to provide generic characterizations of behavior. ASA researchers also plan to contribute to the exploration of stability of equilibria, given that agents' behavior can be only bounded-rational.

The **system transitions and resilience of systems** domain focuses on systems of systems, characterized by complex dynamics, decentralized decision making, and significant uncertainties with the aim of studying system resilience. The behavior of such systems is too complex to be modeled by traditional tools, which is why ASA will experiment with qualitative and quantitative methods and approaches. ASA research in this domain is currently emerging.

Conceptualizing and quantifying resilience – ASA explores different approaches to understanding, evaluating, and quantifying sustainability, including network-analysis based approaches, and qualitative foresight. In 2016-2020 ASA researchers will continue carrying out national economy resilience case studies combining qualitative (e.g., system soft-mapping) and quantitative (e.g., agent-based modeling) foresight methods.

Uncertainty in climate indicators – ASA explores the evolution of "diagnostic" and "prognostic" uncertainty in observations *vis-à-vis* future scenarios, by using greenhouse gas emissions as a template. In 2016-2020 ASA researchers will focus on the issue of limitations in the predictability of emissions. Advanced data-analysis methods, including methods based on coarse-graining of data, will be used for exploring building better (complexity-constrained) projections.

Data analysis revealing behavior patterns – ASA explores newly available data sets, often big data, looking for new insights and stylized facts. In 2016-2020 methods for integration of alternative models from multi-model ensembles and for detecting pre-cursors of unwanted events will be further developed.

Air Quality and Greenhouse Gases Program (AIR)

Formerly the Mitigation of Air Pollution and Greenhouse Gases (MAG) program

NICHE: The IIASA systems approach to air quality and greenhouse gas management constitutes a unique example of a successful science-policy interface that is shaping global, regional, and national policies. Enhanced integration with other IIASA programs and pioneering research into the interplay between rural and urban air pollution will provide the badly needed arguments for measures that deliver local and near-term benefits to different groups in society while also contributing to global and long-term policy targets.

OBJECTIVES

- Develop an integrated approach relevant for urban policymakers in industrialized and developing countries, with intuitive user-interfaces for decision makers and stakeholders who are usually 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 (e.g., transport, indoor household pollution, agriculture), health impacts, and social factors.
- Operationalize the social heterogeneity of the drivers and sources of air pollution and their impacts to design policy interventions that deliver benefits to different social groups and economic sectors.
- Establish the 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 and analyses to explore regional and global benefits of urban decisions.
- Highlight and quantify contributions of specific policy interventions to the achievement of the UN Sustainable Development Goals.

EXPECTED IMPACT: While current IIASA tools and analyses have been designed predominantly for decision making at the international and regional levels, many important decisions fall under the responsibility of urban authorities. A perspective that integrates different problems and policy objectives; time and spatial scales; economic sectors; and technical, economic, and social aspects will provide powerful assistance to decision makers in devising smart solutions that deliver tangible benefits to diverse groups in society.

Objective and rationale

The urgent need for action to secure long-term global environmental and social sustainability is in stark conflict with the widespread short-termism of people and decision makers. However, an integrated systems perspective can offer convincing rationales for policy action with tangible local and near-term benefits while contributing to global and long-term policy targets.

In the past, AIR has established air pollution control as a prime example of integrated approaches that maximize benefits for global climate change mitigation while also delivering immediate local benefits to health and ecosystems. AIR will extend analyses to other policy priorities, with the overarching objective of identifying and promoting practical implementation of science-based, integrated policy portfolios that improve air quality, reduce greenhouse gas emissions, and maximize health, wellbeing and economic benefits for different sub-groups of the population.

Stakeholder awareness of the multiple benefits of an integrated policy approach is limited because it requires an uncommon blend of trans-disciplinary thinking. To overcome this deficit and to facilitate greater understanding among decision makers and stakeholders, AIR will further develop its interactive, next-generation, integrated policy assessment tools for decision support, which enable decision makers and stakeholders to identify packages of policy measures that maximize tangible benefits for different economic sectors and societal groups.

To increase the policy relevance of IIASA research, AIR's analyses will align with the spatial and temporal scales dealt with by current decision making institutions (i.e., individual countries and cities, addressing the next few decades), while embedding these analyses into the global and long-term context of the research conducted by other IIASA programs.

Main strengths and uniqueness

The multi-pollutant/multi-effect systems perspective developed by AIR has shaped the policy approach for air quality management in Europe and guided numerous international negotiations on emission reductions. In the developing world, AIR's systems approach is now also increasingly recognized as an effective concept for solving the pressing air quality problems.

The GAINS model is a well-established tool, developed by the AIR program to identify cost-effective emission control strategies that meet air quality and greenhouse gas emission targets. It has been applied in international negotiations of the Convention on Long-range Transboundary Air Pollution and the EU. It was also used to analyze mitigation efforts for the climate negotiations under the UN Framework Convention on Climate Change (UNFCCC), and for environmental assessments under the UN Environment Programme (UNEP). The GAINS model has been implemented for Europe, China, India, and other Asian countries.

AIR's work is a prime example of the power of systems analysis to bridge the divide between science and policy making, in line with the IIASA mission "*to provide insights and guidance to policymakers worldwide by finding solutions to global and universal problems through applied systems analysis in order to improve human and societal wellbeing and to protect the environment*." The program has developed regular, institutionalized interactions with an increasing number of international policy processes and helped to establish IIASA as a widely recognized provider of impartial scientific

information that is useful for international policy making. There are now institutionalized interactions with, *inter alia*, the Convention on Long-range Transboundary Air Pollution, the air quality and climate policy developments of the EU, the Climate and Clean Air Coalition, the Arctic Council, the World Health Organization, UNEP, and UNFCCC.

The program's unique reputation on the science-policy interface, together with the wide network of collaborating institutions offers an excellent basis for developing and promoting an even more integrated policy perspective that extends the systems approach to other policy priorities beyond air quality and climate.

Key research questions and outlook

Over recent decades, significant progress has been made to reduce air pollution in many parts of the world. However, poor air quality is still the largest single environmental risk for health. A wide array of further beneficial measures remains, opening up scope for policy interventions that serve not only near-term interests but at the same time contribute to global and long-term policy targets.

To facilitate promotion of innovative integrated approaches for decision making, AIR will continue supporting air quality and greenhouse gas policy development of the various global, regional, and national policy institutions, with special emphasis on IIASA member countries. AIR will host, maintain and further improve models and databases for various world regions, and interact with national experts to enhance acceptance.

Furthermore, AIR will continue its global-scale analyses of future emission scenarios for air pollutants and short-lived substances, as an input to global long-term greenhouse gas emission scenarios that are developed at a much more aggregated and stylized level. Special emphasis will be put on the role of policy decisions, both on the introduction of new, more stringent emission control measures, as well as on the effective implementation of existing legislation.

New developments will address, *inter alia*, the following aspects, and integrate them into the assessment framework:

- Non-air pollution related benefits of specific air and climate policy interventions for human health (e.g., physical activity, traffic accidents, and health effects from extreme cold and heat periods, which become more common under climate change).
- Impacts on other policy priorities, including the UN Sustainable Development Goals, malnutrition and obesity, economic development, water pollution, food quality and security.
- The heterogeneity of health and economic impacts of policy measures across different social groups (stratified by gender, income, age, education, etc.), economic sectors and rural/urban populations. Conventional cost-benefit analyses, even those which consider multiple benefits, reveal considerable net benefits to society as a whole for many air quality and climate policy interventions. However, costs and benefits are often different for different actors, and the monetization of benefits does not always reflect the interests of the various stakeholder groups. If groups are to act, they must be convinced that it makes sense for them.
- Impacts on biodiversity of ecosystems, through integrating effects of climate change, fragmentation of ecosystems, and excess nitrogen input.

Ecosystem Services and Management Program (ESM)

NICHE: 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 at improved human wellbeing and sustainable management of the Earth's natural resources. Guiding production and consumption choices that are consistent across scales and compatible with maintaining 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 resources assessment tools.

OBJECTIVES

- Initiate and accompany 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 annually recurrent global commodity market and resources review (including special feature themes such as societal resource-based risks assessment), starting by 2020 with participation of consortium members recruited from IIASA member countries. Create a global (natural/bio-) resources market assessment network or consortium.
- Establish an open-access online 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 eventually be expanded to 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). Launch the CSC web-page/portal in 2016.

EXPECTED IMPACT: Newly designed knowledge systems that drive incremental and transformational policies for ecosystem management and improved human and environmental wellbeing. Resulting portfolios of policy instruments (including observing systems) to be consistent across space, time, and economic/environmental sectors.

Objective and rationale

ESM's strategic goal has been to support policy processes in developing rational, realistic, and science-based strategies for the production of food, feed, fiber, and bio-energy that sustain ecosystem services and safeguard food security. By using advanced theories of applied systems analysis, new information technologies, and integrated biophysical, social, and economic modeling techniques ESM is charting possible solution pathways by linking ecosystems, society, policy, and governance. Today ESM tools are used by national governments and international organizations as an integral part of policy making.

ESM has succeeded in creating a model cluster that integrates all of the major sectors involved in competition for land-based resources. The model cluster was purposefully designed to overcome the "stovepipe problem" of isolated sector approaches to policy change. ESM tools allow for high-

resolution, sector-specific assessments in a total land resources context, often leading to coordination between agencies or ministries. Another objective of ESM modeling is to create methodologies for globally consistent regional, national, and local assessment of land management strategies. All ESM models are implemented on a global level and allow for seamless and hierarchical geographic scaling, ideally in partnership with local partners from IIASA member countries.

From the start it has been the objective—in line with the tradition of applied systems analysis—to create a cluster of modularly linked data and model systems forming a consistent biophysical and socioeconomic policy tool focused on land related resources. The ESM tools can thus be flexibly linked to all of the other quantitative IIASA assessment tools which is in line with the institute-wide strategy of building an integrated assessment modeling cluster across IIASA programs. This strategy of bottom-up data-driven systems representation implies reliance on smart data acquisition strategies. ESM has invested in building and testing novel citizen science approaches to help improve the input datasets needed for ecosystem service assessments. These data feeds, mostly focusing on land-cover and land-use attributes derived from extensive crowdsourcing campaigns, are contributing to new authoritative input datasets for the ESM modeling cluster and the modeling community at large (e.g. the Group on Earth Observations Global Agricultural Monitoring and the International Food Policy Research Institute's Spatial Production Allocation Model).

Main strengths and uniqueness

ESM is currently the world's largest integrated land-use model cluster. It is the only model cluster which has a detailed biophysical base for ecosystem management covering all land classes involved in competition for land. ESM is also unique in its commitment to high input data quality. The Earth Observation Systems (EOS) group of ESM, which is a pioneer in crowdsourced land cover and the founder of Geo-Wiki, is one of Europe's leading groups on citizen science. ESM's Agro-Environmental Systems (AES) group, in cooperation with external partners, has built an agronomic model with explicit representation of crop management and a large array of environmental impacts Environmental Policy Integrated Model (EPIC). The focus on detailed crop and grassland management for comprehensive sustainability assessments on global scales and the generation of the necessary input data sets is unique in the world.

Likewise, ESM has built the only global forestry model which explicitly treats forest management (Global Forest Model, G4M). This forestry model is linked to the forest sector module in the Global Biosphere Management Model (GLOBIOM) constituting the only global forest sector model currently in operation. GLOBIOM is considered as one of the leading global land-use models and at the same time also one of the leading agricultural sector models. GLOBIOM is used by many national and international organizations in both the developed and developing world for detailed policy impact studies. This suit of unique land-use models is completed by the techno-engineering model BeWhere. The widely applied model is a highly resolving decision and policy support tool including a singular supply-chain depiction that optimizes location, capacity, logistics, and emissions of renewable energy systems. Furthermore, ESM runs the 'rapid assessment' model FeliX—based on a systems dynamics approach. FeliX serves to 'mock-up' complex Earth systems, capturing vital mechanisms and facilitating insights into areas such as ecosystems, agriculture, biodiversity, energy, climate, water, disasters, health, and weather.

Key research areas and outlook

ESM is committed to the following key research activities:

- Investing in building and testing novel citizen science approaches to help improve the input datasets needed for ecosystem service assessments.
- Continuing to test new approaches to model stochastic events and associated ecosystem based risk mitigation.
- Continuing to link to other IIASA models to build an IIASA integrated assessment modeling cluster (e.g., linking to IIASA energy models).
- Implementing linkages to external earth system models to assess large-scale feedbacks from management-induced ecosystem change.
- Building new policy engagement strategies to generate more transformational policy impact.

Crop modeling. ESM's AES group will continue with core development of ESM's EPIC infrastructure, with a focus on including a global grassland module. The group has already started simulations to estimate site-specific crop responses to nitrogen and water application rates. A machine-learning algorithm using Bayesian network model will be developed to help assimilate information from the detailed biophysical model runs, remote sensing, in-situ data, and crowdsourced information. AES will take part in the inter-comparison phase of the global modeler's community in Agricultural Model Intercomparison and Improvement Project's Gridded Crop Modeling Initiative (AgGRID). The group will also work on improving soil data input for EPIC, working towards increasing spatial resolution and quality of soil data and developing a specific phosphorus routine.

All of these large-scale, biophysical datasets will form a knowledge system with the aim of providing the basis for a global service-provision hub. The necessary investment to build knowledge infrastructure that is continuously learning and provides services to a community of millions of producers, businesses, non-governmental organizations and governmental organizations will require much of the resources to be sourced over the next five years.

The IIASA Citizen Science Center: Engaging citizens in environmental monitoring. The IIASA Citizen Science Center (CSC) is dedicated to research into the growing opportunities arising from spatial citizen science to address the most pressing areas of global change. The CSC will be a cross-cutting platform to encourage both the uptake of citizen science across many of the IIASA programs and linkage to European and global initiatives. A number of recent IIASA citizen-science campaigns have been completed or will be extended in the near future. FotoQuest Austria, for example, in which citizens collect photos of the landscape, which is being extended to other countries in Europe through the European Cooperation in Science and Technology network TD1202 *Mapping and Citizen Sensor*. Picture Pile, the next generation game that will follow on from the success of Cropland Capture and focus on forest cover and deforestation. ESM is planning to further expand the CSC in the near future from land cover to other fields such as urban areas (working with the World Urban Database and Access Portal Tools WUDAPT, for instance), energy, food security, and air pollution.

Another example of applying citizen science is the development of the Biomass Geo-Wiki platform, which will host in-situ biomass measurements from around the world as part of the newly proposed International Forest Biomass Network. These types of data are crucial for the calibration and validation of remotely sensed data, in particular for the future European Space Agency Sentinel-2 and

BIOMASS missions. This work complements ongoing projects including GlobBiomass and the Independent Monitoring of Greenhouse gas Emissions.

LACO-Wiki is one of the most recent additions to the EOS suite of tools, which is an open-access, online validation platform offering standardized validation functionality for map users and producers. The overall aim of LACO-Wiki is to become a repository for calibration and validation data to help create more accurate land-cover maps in the future.

GLOBIOM development. GLOBIOM provides the platform for integration of the multiple data and modeling streams at ESM and beyond. It also allows these data streams and models to be coupled to other models. ESM's Environmental Resources and Development (ERD) group will pursue the second generation integration with the EPIC and G4M models which will further improve the consistency in bio-physical and economic assessments across land-use sectors.

As land use is key to the provision of negative emissions, which may be necessary if the climate change is to be stabilized below 2°C, GLOBIOM will also be integrated with the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) within the Shared Socioeconomic Pathways scenario framework.

In collaboration with the Water Program, links between GLOBIOM and hydrological models will be developed. The current status and future challenges to food security in the developing and developed world will be a main focus of model development, involving many external collaborative projects. The particular role of the GLOBIOM team will be to bring the well-known IIASA expertise in building globally consistent, forward-looking scenarios where climate change plays an increasingly important role. A major scientific challenge will be to develop, together with the World Population Program, a new version of the GLOBIOM model to analyze the effects of extreme weather events on agricultural markets by integrating the long-term projections tool of GLOBIOM together with a newly designed econometric short-term prediction tool covering also non-food commodities.

The GLOBIOM model has been extensively used by European and US agencies for assessments of how bio-economy development will affect greenhouse gas emissions. The forest module in GLOBIOM will also be further developed to better capture the notion of circular economy, one of the key approaches to sustainable development.

The GLOBIOM model will be used to assess the impact of current and future policies on deforestation and biodiversity in tropical countries through the Tropical Futures Initiative and through major outside funded projects. The aim is to build regional, national, and local capacities in land-use change modeling. Several training workshops will be held in IIASA member countries to strengthen national land-use policy processes by providing a sound scientific base.

Originally initiated by the cross-cutting socioeconomic heterogeneity project, a further development of GLOBIOM is to improve the socioeconomic heterogeneity of the model itself as well as the production system side. After an initial investigation phase to identify existing databases and methods, we will be looking at quantification approaches to refine food-demand projections for GLOBIOM, based on detailed accounts on population education, aging, income, and urbanization. These sources of heterogeneity will also be used to better represent impacts of food price shocks in GLOBIOM. Linkage to high frequency household data using the internal crowdsourcing capacity will help to further improve the quantification of consumer choice.

Given the growing importance of fish in human diets—protein production from farmed fisheries is exceeded only by beef—and the manifold trade-offs between terrestrial and aquatic food production, in the next five years ESM will work to transform GLOBIOM from a pure land-use model to a land-oceans model.

Other areas of further application and development include the assessment of the indirect impacts on land use via biofuels, other non-food products, and consumer behavior in terms of dietary shifts. GLOBIOM is also perfectly suited for evaluation of resource-efficiency policies aligning with the circular economy concept.

Energy Program (ENE)

NICHE: While energy underpins all human activities and is central for human wellbeing, the current unsustainable use of energy is the source of major environmental, social, and economic challenges. ENE research spans many domains, including research in energy security, energy and poverty, and energy-environment links, and necessarily adopts a holistic and integrated perspective. A main strength of the program is its ability to understand salient trade-offs and synergies between multiple policy priorities and objectives in different sectors.

OBJECTIVES

- Develop the next generation of ENE's integrated assessment Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) with an improved representation of heterogeneities, behavioral change, uncertainty, and the energy-water-land nexus (together with other IIASA programs).
- Develop and quantify a new conceptual framework for energy poverty, moving from energy access to a broader definition of energy for human wellbeing.
- Expand into new areas of research exploring, among others, political factors and how they shape energy system transformations.
- Further establish ENE as a leader in the scientific community, coordinating major international research projects and serving as a hub for important community datasets and services.
- Develop interactive (web) policy tools and hold regular stakeholder workshops, fostering the science-policy dialogue on energy sustainability.
- Establish a broad capacity building platform with key partners from the G20 countries (with a focus on the co-benefits of climate and development policies).

EXPECTED IMPACT: Enhancement of ENE's MESSAGE integrated assessment model will enable novel examination of energy transformations across multiple spatial and temporal scales (considering global to regional dynamics as well as local environmental constraints, such as land and water). Quantitative assessments of the energy needs for poverty eradication will enable policymakers to link energy planning to development goals. Through a number of stakeholder and other processes, ENE aims to increase capacity building and the uptake of this scientific knowledge in regional and international policy making and further enable science to policy dialogues.

Objective and rationale

The long-term goal of ENE is to provide scientific and strategic analysis to better understand the dynamics of future energy transitions, their main driving forces, enabling factors, barriers, as well as their consequences for the social, economic, and environmental dimensions of human wellbeing and sustainability. Energy plays a central role in shaping human and technology systems and their impacts on the natural environment. The program aims to support policy making by studying policy mechanisms that would enable the transformation of the present energy system to a cleaner and more sustainable one. Research activities will include holistic scenario analyses based on large-scale systems engineering and integrated assessment modeling to explore critical feedback of the energy transformation to other sectors, such as competition for land and water resources. ENE will also develop new methods and decision-analytical frameworks to explore energy's role in addressing policy trade-offs between sustainable development objectives.

Scenario analysis and policy applications will be complemented over the next five years by empirical research as well as a number of exploratory projects. A key objective of following this triple research track is to establish an *evidence-based decision support system* informed by historical facts and applied through cutting-edge modeling and systems analysis tools.

Main strengths and uniqueness

The tradition of energy-related research at IIASA goes back to the foundation of the institute, allowing ENE to build on historical strengths and well-established collaborative networks. In particular, ENE's leading role in integrated assessment has fostered various major external but also in-house collaborative activities in addition to the successful completion of the Global Energy Assessment (GEA) in 2012. Over recent years, the program has established itself at the forefront of major energy and climate research community activities. For example, ENE coordinated major parts of the Intergovernmental Panel on Climate Change's Fifth Assessment Report, and served as a hub for community data services.

From a methodological perspective, ENE's core competencies include modeling and scenario approaches based on endogenous technological change, integration of energy-economy-environment interactions, energy end-use and services, uncertainty assessment, integrating socioeconomic heterogeneity into energy models, and policy analysis. Over the years ENE has enhanced and extended its integrated assessment framework, MESSAGE, by linking it with other tools at IIASA such as the Global Biosphere Management Model (GLOBIOM). The program has also developed novel operational methods going beyond the often simplified (deterministic) representation of energy, economic, and environmental interactions. A recognized strength of the program is the systematic and holistic analysis of energy policy objectives and their interactions, in order to identify possible synergies and trade-offs. This entails moving beyond a single-objective focus in the assessment of future energy transitions to address a range of energy-development objectives simultaneously, which are at the same time robust against multiple uncertainties.

Other features of the ENE modeling tools comprise the explicit representation of heterogeneities, such as rural and urban energy use, or other behavioral, social, and economic heterogeneity. These factors are critical for understanding consumer choices, distributional impacts, and effectiveness of energy policies, which has in recent years become a key strength of ENE research.

Key research areas and outlook

The program's research strategy for 2016-2020 will combine applied research with a focus on integrated assessment, energy policy modeling, empirical policy analysis, and exploratory research projects with a strong methodological focus.

Integrated assessment (IA) work will be geared toward the identification of linked solutions in order to simultaneously address major energy-related challenges and their links to other sectors, such as food and water. Particular emphasis will be given to the development of new methods to assess trade-offs and synergies among different objectives in order to identify regional and global "win-win" strategies. ENE will also continue to assess and quantify the energy dimension of poverty.

Modeling possible future policies will be complemented by empirical assessments in order to better understand political constraints but also opportunities that might enable or accelerate the energy transformation. Finally, methodology development will focus on (i) deepening heterogeneity in energy modeling, (ii) technology diffusion, (iii) behavioral changes, and (iv) uncertainty.

Integrated assessment of energy and its linkages to other sectors. There are many links among the energy system and other resources and production systems; most notably among energy, water, and food supply systems. With economic development, population growth, and changing diet and lifestyles projected for the future, competition among different sectors for limited resources is expected to increase, and could constrain future energy-system transformation options. It is therefore important to capture the links among sectors to evaluate how developments within each sector may impede or facilitate the transformations of others. The ENE Program will take a three-pronged approach to improving the representation of multi-sectorial interactions in energy models: (i) improved representation of water and land resource requirements within the energy system; (ii) enhanced collaboration with other IIASA programs to develop explicit links among energy, land use, and water models; and (iii) development of a next-generation, spatially-explicit, energy-systems model that can better capture the local nature of water and land-use constraints and match the resolution of existing water and land-use models to facilitate integration.

These developments will enable the program to assess the implications of water and land-use constraints for energy-system transformations and climate-mitigation strategies, including evaluation of adaptation strategies in the energy sector that could alleviate such constraints (e.g., less water-intensive cooling systems). In addition, the implications of different energy-system transformations for other sectors will be examined (e.g., the impacts on water and food supply systems and natural ecosystems). The ultimate goal is to identify integrated solutions and policies that can more efficiently address the multiple challenges and development goals across sectors.

Energy and Poverty linkages. Building on the success of the last five years in understanding household energy poverty—the lack of access to clean cooking fuels and electricity—ENE will continue to assess and quantify the role of energy in meeting other human needs, such as food, shelter, and mobility. Catalyzed by the recent European Research Council Starting Grant awarded for studying "Decent Living Energy," the energy and emissions thresholds for providing decent living standards to all, the ENE group will use empirical methods to assess the material basis of poverty, the consumption patterns of rising income in developing countries, and their relationship to technological change. This empirical analysis will feed into system models to calculate the energy requirements in different regions of the world to

eradicate poverty, and the related environmental impacts of this energy growth, including air pollution and climate change. This expanded module on energy and poverty will be linked to the integrated assessment framework to enable disaggregated and enriched views of future socioeconomic development and of their related climate-change impacts.

Understanding drivers of energy policy choices. A main focus of ENE over the last five years has been on understanding trade-offs and synergies between multiple policy objectives under different policy choices using integrated assessment models. But how do these multiple objectives play out in the real world? And is there a hierarchy between different objectives? Energy policy choices are made based on both hard constraints of the energy system (geographic, economic, and technological) and political perceptions of what types of energy are desirable (e.g., the availability of stable suppliers, the safety of nuclear power, or the importance of curbing greenhouse gas emissions). The overarching aim of ENE research in this area is to identify when and how political factors will play an important role, and particularly explore to what extent political, institutional, or governance factors may constrain or enable certain policy options.

Teasing out these dynamics between hard energy system realities on the one hand and softer political priorities on the other, is crucial to providing policy-relevant and realistic advice on dealing with energy challenges. It requires both a techno-economic and political understanding of energy systems. ENE's work on this interaction takes advantage of the group's expertise in energy systems analysis and understanding of hard constraints combined with its experience in working across different disciplinary domains in the field of energy security. Ultimately, ENE can help identify the preconditions for transformative energy policies and inform the construction of both techno-economically and politically feasible energy transformation pathways. This research agenda requires empirical work to identify historical preconditions for transformative energy policies, and modeling work to integrate the political constraints into the depiction of future energy pathways.

Representing heterogeneity as driver of energy system changes. A frontier research area for ENE is to more fully incorporate consumer heterogeneity and behavioral realism into its integrated modeling framework, MESSAGE. Rather than representing consumer behavior and the end use of energy as a simple rational choice between available alternatives, ENE will improve its modeling framework to consistently represent the abundant empirical evidence showing that real-world decision making is complex and not routinely rational.

Deepening the representation of heterogeneity and behavior in energy modeling is a major challenge, and can take many forms. ENE research will concentrate on those areas which are critical for assessing energy transitions, considering a variety of policy-relevant sustainable development objectives. For instance, more refined modeling will take account of distinctions between urban- and rural-based consumers, particularly in the residential and transport sectors. The careful consideration of different consumer types (e.g., early adopters, late adopters, and so on) will help to capture the complexities of the technology diffusion process. This research will result in improved modeling of the drivers of energy-use and technology acquisition among diverse individuals in the population. The sum of these disaggregated decisions ultimately determines the outcome of the entire system, but perhaps more importantly, the representation of these heterogeneities will enable the assessment of differentiated policy instruments that target certain types of individuals and could lead them to choices with more socially-optimal and equitable outcomes.

Exploratory research: technology, behavior, and uncertainty. While technological change has been a major driver of the historical transformation of the energy system, the diffusion of individual technologies has been dependent on adoption by consumers and their behavioral patterns. Understanding how technology and behavior interact and whether they enable or constrain energy transitions is therefore central for building future scenarios that are based on historical evidence.

Building upon early ENE research in the areas of spatial technology diffusion, technology supply markets, and vehicle choice modeling, ENE is planning over the next five years to expand its modeling efforts in these areas in order to better represent critical determinants of technology diffusion and behavioral change. The ultimate aim of this research is to operationalize the new concepts beyond simple stylized tools, and to integrate them into the detailed large-scale energy systems and integrated assessment models of the ENE Program.

In addition, the systematic exploration of uncertainties in the areas of technological development and behavioral change will remain a cornerstone of ENE's research activities. Neither technological nor behavioral change can be forecasted accurately over long timescales. Robust policy insights therefore require a formal treatment of uncertainty. To this end, ENE will develop and apply techniques for robust decision making under uncertainty, including systematic sensitivity analysis to explore parametric uncertainties.

Evolution and Ecology Program (EEP)

NICHE: Adaptations are key to understanding living systems: agents adapt as systems change. In social dynamics, behaviors adapt through individual and collective learning, subject to bounded rationality and cultural dispositions. In biological dynamics, genes adapt through evolution under natural and anthropogenic selection pressures. Addressing these universal challenges in managing the biosphere, EEP devises, analyzes, and calibrates models of complex adaptive systems.

OBJECTIVES

- Develop new tools for integrating biological, social, and economic dimensions in assessments of fishery systems.
- 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 community-orchestrated protocols for integrating evolutionary change in annual fisheries assessments.
- Build awareness of dangerous biases in recognizing systemic risks.

EXPECTED IMPACT: These targets will have impacts on three levels: (i) by raising global awareness that rapid adaptations cannot be ignored if living systems are to be understood, predicted, and managed; (ii) by serving as a widely recognized international hub for the development of cutting-edge innovative methods for analyzing complex adaptive systems; and (iii) by pioneering applications to topical case studies, pushing the envelope of insights from systems analysis.

Objective and rationale

Developing new methods and pioneering their applications, EEP analyzes and forecasts how ecological and evolutionary dynamics shape populations, communities, and ecosystems, and how behavioral adaptations, incentives, and regulations determine social dynamics among stakeholders.

Modern approaches to describing complex adaptive systems need to account for non-linear feedbacks; non-equilibrium dynamics; discontinuities and break points; collective phenomena; systemic transitions; behavioral dynamics; and multi-level and multi-scale interactions among processes and agents. Ecology is the quintessential systems science, dealing with such challenges in a holistic way. This approach is complemented by studies of adaptation and evolution, to account for the ubiquitous capacity of systems and agents to alter their features and interactions in response to environmental change. Applied mathematics and theoretical physics contribute advanced tools to the diverse mix of methods that is characteristic of EEP's research.

On this basis, EEP is building bridges between approaches to systems analyses of the living world that are policy-relevant; theoretical and empirical; biological and social; and mathematical and computational.

Main strengths and uniqueness

Dedicated to systems thinking, interdisciplinarity, and methodological innovation, EEP is one of the few research groups around the world that focuses on interfacing – systemically and across a broad spectrum of topics – cutting-edge fundamental research in theoretical ecology, evolution, and game theory with policy-relevant insights into the global and universal challenges facing humankind.

A distinctive feature of EEP's research is its integrative focus on human and natural systems. In particular, powerful methodological synergies and innovation opportunities result from recognizing processes of adaptation as key common characteristics of both biological and social systems. For this reason the program has developed a versatile and pluralistic toolbox of models and methods for integrated assessments of ecological, evolutionary, environmental, and social dynamics.

The program is particularly internationally competitive in evolutionary fisheries science, research on speciation and community models, and cooperation studies. Many of EEP's researchers are highly regarded in their field, as evidenced, for example, by top-ranking h-indices.

EEP uses a strongly network-oriented research approach, combining contributions by scientific leaders from around the world who work as part-time IIASA research associates with the work of young scientists, visitors, and other collaborators, especially from IIASA member countries. EEP is currently collaborating with scientists from over 100 research institutions in over 25 countries.

Key research questions and outlook

Building bridges among many traditional divides, EEP strives for the increasingly powerful integration and widening scope of systems approaches to managing the world's biosphere. This overarching synthetic objective will be pursued in the topical areas below.

Fishery Systems. EEP research on fishery systems will be developed in two main directions. First, EEP addresses missing interdisciplinary links in contemporary fisheries science and develops tools for integrated bio-socioeconomic assessments of fishery systems. The objective is to help surmount the currently widespread practice of assessing a fishery's biological subsystem in quantitative detail, while human dimensions and ecosystem services are brought into the analysis only qualitatively, and often haphazardly. Second, EEP seeks to overcome a blind spot in the management of living natural resources: over time, exploitation not only changes their abundance, but also their heritable traits. With harvest mortalities often exceeding natural mortalities by a wide margin, adaptive responses of wild populations to the altered selective environments caused by their exploitation are inevitable. These evolutionary dimensions of harvesting have been overlooked for decades and now need to be integrated into current management practices and protocols. For this purpose, EEP is developing—together with an international consortium anchored in the Working Group on Fisheries-Induced Evolution of the International Council for The Exploration of the Sea—a standardized approach and associated computational tools for assessing fisheries-induced selection pressures across a large range of species and stocks.

Biodiversity Dynamics. EEP's biodiversity research will be pursued in four dimensions. First, EEP will build on its internationally leading position in understanding processes of biodiversity formation by devising models that increasingly do justice to the complex features of real-world speciation processes. A particular objective is to gain insights into the determinants of biodiversity formation by developing new statistical techniques for inferring past speciation processes from present biodiversity patterns. Second, the current line of EEP's ecosystem models will be extended to describe biodiversity patterns at the community level in ways that are eco-evolutionarily consistent, calibrated to empirical observations, capable of predicting biodiversity responses to anthropogenic environmental disturbances, and account for spatial heterogeneities. Third, EEP will develop and establish new applications for ecological and evolutionary models pioneered by the program, by extending: adaptive dynamics theory (for predicting selection pressures in realistic ecological settings); the eco-genetic modeling framework (for predicting evolutionary adaptations to climate change); moment dynamics (for predicting spatial ecological heterogeneity); and microbial dynamics (for predicting key determinants of agricultural productivity and terrestrial carbon fluxes). Fourth, EEP will co-lead a series of international IIASA workshops devoted to developing a next generation of global vegetation models informed by concepts, insights, and methods from evolutionary theory.

Global Health. Contributing to the growing emphasis on global health challenges in IIASA research, EEP will work on analysis to further understanding of the dynamics of infectious diseases. Research will seek to elucidate rapid contemporary evolution in disease virulence and host resistance and develop transmission models for vector-borne diseases, such as malaria, that can account for the effects of climate change. The effectiveness and efficiency of alternative intervention strategies for disease eradication will also be assessed.

Equitable Governance. Contributing to the IIASA cross-cutting project on the Equitable Governance of Common Goods, EEP will provide scientific options for designing institutions for protecting common goods. The need for such protection—which arises whenever the selfish interests of individual agents differ from the collective interests of their group—pervades most global challenges addressed by IIASA. Examples include protections against climate change, pollution, natural disasters, resource overexploitation, and social-security abuse, among many others. These efforts will unfold in three

interrelated directions. First, research will analyze how, contingent on the characteristics of specific situations, regulatory options can best be combined with positive and negative incentives. Second, research to devise a framework for facilitating stakeholder reconciliation is ongoing. Third, research on bounded rationality and cultural diversity will account for inevitable complexities of human behavior, which are largely ignored by current models of cooperation evolution.

Systemic Risk. Contributing to the IIASA cross-cutting project on Systemic Risk and Network Dynamics, EEP will develop options for measuring, predicting, mitigating, and counteracting the dangers of cascading failures spreading across networks. Such perils, known as systemic risks, are common to a large variety of networks in today's increasingly interconnected world, including those underlying trade, transportation, financial services, utility supplies, the internet, ecosystem services, and disease transmission. EEP research in this area will focus on three facets: analyzing collapse dynamics in ecosystems to understand the observable structural features that make up their resilience; developing new methods for pattern-based time-series analysis to reveal patterns that precede unwanted events and can therefore serve as early-warning signals; and understanding how and why humans systematically misperceive systemic risks and which factors might worsen the danger of such misperceptions.

Nexus Research. Contributing to the IIASA Nexus++ cross-cutting project, EEP will work on several interfaces between traditionally disjointed areas of research. Particular efforts will be devoted to studies that bridge the following divides: (i) among yield-oriented, biodiversity-oriented, and economically oriented analyses of fishery systems, (ii) between cutting-edge research on biodiversity formation and applied research on biodiversity conservation, (iii) among the epidemiological, ecological, and evolutionary dimensions of disease dynamics, (iv) among economical, sociological, psychological, anthropological, and evolutionary approaches to human behavior, and (v) among the areas in network theory which enable the determination and mitigation of systemic risks.

Risk and Resilience Program (RISK)

Formerly the Risk, Policy and Vulnerability (RPV) program

NICHE: The major risks facing the world—from extreme events, food and water security, to global climate change—are complex, systemic, and far-reaching. Building on a history of risk research, RISK is well positioned at IIASA to take an interdisciplinary, systems perspective on risk policy problems with the vision of transforming the way societies manage these risks while confronting the global trends amplifying them. RISK puts strong emphasis on enhancing the resilience of vulnerable communities, countries, and regions.

OBJECTIVES:

- Develop the next generation of RISK's Catastrophe Simulation Model (CATSIM) to incorporate interdependent risks (using copulas) and longer-term scenarios, with applications to flood resilience, the Loss and Damage Mechanism, Nexus++, UN Sustainable Development Goals (SDGs), and other RISK risk topics.
- As part of the Flood Resilience Alliance, co-develop innovative resilience measurements and management methods and tools.
- Expand into new areas of risk research exploring contributions to the energy-water-nexus and how to achieve the SDGs.
- Further develop and apply RISK's participatory process design incorporating heterogeneity of stakeholder views (plural rationalities), 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.

EXPECTED IMPACT: Through research and active engagement, this work will influence deliberations on the UN International Mechanism for Loss and Damage (Loss & Damage Mechanism), and the Sendai Framework. RISK's analytical tools for measuring and enhancing resilience will be used by institutions around the world, aiding a large number of vulnerable households by 2020. Building on RISK's model-based stakeholder process design, policy across multiple risk issues will be improved, with an immediate focus on renewable energy in the Middle East and North Africa (MENA) region and Europe.

Objective and rationale

The objective of RISK is to contribute to transforming the way societies manage risks to economic, ecological, and social systems while confronting the global trends that are amplifying these risks. RISK is addressing, either directly or indirectly, critical global risks with particular focus on two major topics: (i) extreme (climate-related) events, and (ii) investments in large renewable energy facilities. For both topics, RISK puts strong emphasis on enhancing the resilience of vulnerable communities, countries, and regions. RISK research has contributed to four of the six research areas structuring IIASA activities according to the institute's Strategic Plan 2011-2020:

- *Food and Water:* research on food security risks, and risk of floods, droughts, and other climate extremes as they impact on households, communities, and countries.

- *Energy and Climate:* research on climate adaptation via analysis of extreme events and climate mitigation via analysis of renewable energy technologies in the MENA region.
- *Poverty and Equity:* examination of safety nets against catastrophic natural hazards to reduce disaster-related poverty traps, and contribution to building resilience of low-income communities.
- *Advanced Systems Analysis:* synthesis of "one-sided" disciplinary approaches into an integrated view linking quantitative methods (risk and economic modeling, advanced methodologies for estimating extreme "fat tail" risk) with qualitative methods (surveys, policy analysis, deliberative process, cultural theory). RISK is unique at IIASA in structuring expert-stakeholder deliberative processes that bridge the gulf between systems models and practical policy options.

RISK's work is organized around five strongly interrelated areas: (i) risk analysis and modeling; (ii) understanding disaster resilience; (iii) socioeconomics of risk management and climate strategies; (iv) risk pooling and sharing; and (v) risk governance. Work in these themes is complemented by leading RISK involvement in two key IIASA cross-cutting projects: Systemic Risk and Network Dynamics, and Equitable Governance of Common Goods, as well as the externally funded project on Flood Resilience.

Main strengths and uniqueness

The hallmark of RISK's research is the integration of multiple strands of mathematical and social science research. RISK continues to develop state-of-the-art methodology for assessing risks, and designing and carrying out expert-stakeholder deliberative processes that bridge the gulf between systems models and practical policy options. RISK is not alone in confronting the challenges presented by critical global risks, at the same time, RISK has features that—taken together—distinguish it from other risk-focused research organizations, and enable it to work effectively at the science-policy-society interface. These include:

- *Renowned history of risk research:* RISK benefits from the history of risk research at IIASA, dating back to the early 1970s, when IIASA established itself with its studies on risk perception, public acceptance of risky technologies, social constructions of risk, institutional/risk governance, and innovations in stochastic and probabilistic risk assessment methods.
- *Multiple disciplines:* RISK expertise includes physics, mathematics, statistics, modeling, economics, decision science, sociology, geography, political science, and anthropology. This interdisciplinary mix and resulting methodological innovations (ranging from the mathematical copula approach to the design of stakeholder processes) has proved essential for RISK's policy interventions, and will enable the program to flexibly respond to future science-policy issues. RISK's diversity has also fostered young researchers to apply to RISK as part of the IIASA Young Scientists Summer Program and Postdoctoral Program.
- *Systems approach:* Interdisciplinary research is at the heart of systems analysis, since a mix of disciplines enables the multiple perspectives on the physical, economic, ecological, and social aspects of an issue which are needed to work effectively in both the science and policy arenas.

In terms of competitive edge for the next five years, RISK sees the following opportunities:

- Risk management is gaining recognition in climate change research and other tangential areas, with greater emphasis on social sciences, economics, and equity.

- Risk and equity are increasingly becoming cross-cutting issues at IIASA, with high potential to analyze co-benefits of joint strategies.
- Increasing broad-based interest by funders and policymakers in science for partnerships that bridge the implementation gap at international, national, and local levels.

Key research questions and outlook

Intensifying ongoing research topics

RISK's work on critical risks with its emphasis on climate extremes and investments in renewable energy will continue in the near term, yet with important reflections and added emphases in the medium-to long-term.

Evaluating (climate) risk management: *How to help transform disaster risk management towards a broad resilience perspective?* A high priority of RISK is identifying cost-effective and comprehensive measures for building resilience of the poor and vulnerable across global to local scales. Equally important is identifying support mechanisms and incentives through insurance/safety net programs, and RISK will continue its already intensive work on investigating how insurance has promoted (or discouraged) risk reduction. At the same time, RISK will proceed to inform decisions more holistically on reducing disaster risk as part of development choices.

Work on this topic builds strongly on CATSIM. RISK pioneered the original development of CATSIM as a first of its kind decision-support tool for global, regional, and national policymakers. The intent is to periodically measure a country's or region's progress towards socioeconomic resilience. As such, significant continuity in the approach is necessary to ensure that the RISK method is seen as familiar and dependable by policymakers involved. RISK will build on these achievements and address new and emerging issues.

Methodologically, this involves the integration of climate and socioeconomic development scenarios up to 2050. Working together with colleagues across programs, RISK is incorporating macroeconomic output scenarios based on human and physical capitals projected in the Shared Socioeconomic Pathways (SSPs) to examine future risks of climate extremes and how they are linked with other longer term trends, such as demography and public debt trajectories. We foresee that this type of analysis can better inform new initiatives at IIASA such as the Nexus++ and work on the SDGs.

RISK will also continue its unique collaboration along the science-policy-society interface on resilience interventions at multiple scales from local to international, extending the work of the Flood Resilience Alliance, which brings together the insurance, humanitarian, and development sectors. The team has developed a systems framework for measuring and placing resilience in a development context. This framework serves as the basis for community interaction for identifying actionable paths to strengthen resilience and will be further augmented using models and tools, such as a system dynamics model, which will also serve as the backbone for informing innovative participatory approaches, such as policy exercises.

Equity and the Loss & Damage mechanism: How to build equity regarding process and outcome into negotiations regarding climate-related burdens that are beyond the limits of adaptation? RISK has already had substantial impact to the framing of the new Loss & Damage mechanism, which addresses

climate change loss and damage in the most vulnerable countries. RISK contributed papers and a proposal to the climate negotiations and was recently invited by the German government to participate in proposed work along the same lines under the G7 Forum. One focus of future work on the Loss & Damage mechanism will be to inform policy and set up a hub for researchers, policymakers, and leading non-governmental organizations.

Governing the energy transition: What are the communication and perception stumbling blocks in energy transitions? RISK is finalizing research that supports the implementation of a communication strategy for siting electricity transmission lines, which are necessary for Germany's energy transition. RISK is also engaging in a project involving stakeholders in the MENA region to develop a renewable energy strategy. This work will continue with a focus on Egypt and Morocco, as well as a new research project on implementing Austria's ambitious program for regional renewable energy independence.

Participatory process design: How to evaluate risk-based policy options that are effective, robust, and acceptable? RISK work on participatory process design has been innovative in terms of co-producing options for the deliberative process. This work is being extended in two directions. As part of the resilience research, RISK is developing policy exercises/gaming processes to be applied for the co-generation of policy options to bolster resilience. This work is being carried out with a variety of stakeholders across community, sub-national, and national scales in Indonesia, Nepal, and Peru. In collaboration with other institutions, RISK also seeks to integrate the concepts of robust decision making and plural rationality theory, and test this approach in a participatory process for risk management.

New research topics

IIASA plans to pursue holistic, integrated assessments of pathways leading to the SDGs which present exciting opportunities and also challenges for RISK in contributing to this new research direction.

The role of extreme events for the food, water, and energy nexus. The risks from extreme weather events are projected to worsen with climate and socioeconomic changes and will likely have a tremendous impact on the effort to achieve the SDGs; particularly with regard to food security, water availability, and energy generation. The challenge for RISK is to determine how its advanced expertise on probabilistic risk analysis, multi-actor and multi-criteria analyses, resilience, and expert-stakeholder processes can enrich relevant scenario analyses and modeling results.

A risk perspective on the SDGs. The IIASA TWI2050 project might benefit by considering a risk management perspective to account for up- and down-side risk taking. Addressing the SDGs from the point of view of a risk analyst would have the advantage of access to a large and interdisciplinary risk research community, bringing to bear social science and mathematical traditions. The challenge for RISK would be to broaden its research portfolio to encompass the multiple risks that are salient to the integrated pathways needed to achieve the SDGs.

Contribution to health exploratory project. RISK is keen to extend its focus on critical risks towards impacts on human health and health systems, in line with planned cross-cutting efforts underway at IIASA. The challenge will be to identify broad-based links between risk analysis and health research that can be used to robustly inform relevant policy options.

Transitions to New Technologies Program (TNT)

NICHE: Technology is central to human development and achieving sustainable futures. Research at IIASA focuses on the core causes of technological change and on policies for development and diffusion of fundamentally new technological systems. Large networks, in-house databases, and modeling frameworks have been developed, making IIASA an institution uniquely positioned to address technological change from an interdisciplinary and international perspective, and inform policy measures for achieving a sustainable future.

OBJECTIVES:

- Develop databases on technology scaling, associated emission uncertainties, technology combinations, productivity increases, and general measures of technological change.
- Develop operational concepts and development needs critical for land-energy-water interactions using a systemic innovation approach.
- Extend systems analysis to technologies identified as critical to resolve conflicts between the UN Sustainable Development Goals (SDGs, via the The World in 2050 (TWII2050) project and demonstrate which technology and policy combinations can achieve viable synergies across the all 17 SDGs by 2020.
- Identify key gaps in research and development efforts, niche market creation, and investment to provide timely advice regarding possible development roadmaps to multilateral and national funding and technology agencies. This work will include policy brief documents and a series of policy exercises or workshops.
- The SDGs are the shorter-term goals of the long-term transformation toward prosperity for all within planetary boundaries. New technologies are required on unprecedented scale for creating future systems that can simultaneously fulfill all 17 SDGs. TNT is planning a portfolio of outreach activities based on the program's research which will include policy briefs and stakeholder consultations with policymakers, civil society, private sector, and science and engineering communities.

EXPECTED IMPACT: The next technological revolution toward sustainability will most certainly transform the world. It poses huge opportunities as well as threats for humanity. The main policy impacts of TNT's work will involve the development of pathways that can achieve multiple benefits from technological change. By 2020, TNT will help integrate innovation and technological change, will engage in community research activities, and will provide policy advice on topics from the SDGs to national technology roadmaps.

Objectives and rationale

The strategic goal of TNT is to further the understanding of the patterns, drivers, constraints, and impacts of technological change. The focus is particularly on systems that are key for achieving global sustainability. The ultimate objective is to identify viable options and policies for accelerating transformation towards a sustainable future for all. Another key objective is to develop an integrated systems perspective on innovation and technological change across all IIASA programs through a strong inter-program and interdisciplinary research agenda. These research activities include the development of shared methods, tools, and data, for policy-relevant research findings and for contribution to major international initiatives and assessments (Intergovernmental Panel on Climate Change (IPCC), International Panel on Social Progress (IPSP), TWI2050, Sustainable Energy for All (SE4All), among others).

The main drivers of global change and the core resources for addressing sustainability challenges are people and their technology. These two principle drivers of past and future global transformations are the thematic research focus of two IIASA programs (the World Population Program and TNT). These drivers define the relationships among all forms of natural capital (land, water, energy, atmosphere) and the services they provide (food, energy, material wellbeing) which are the subject of the applied research programs at IIASA. Technology comprises both social techniques (norms, institutions) as well as technological hardware (processes, products, and infrastructures). In other words, takes the form of disembodied and embodied knowledge. It is, together with human knowledge, the only truly renewable resource. Technology is a key determinant for which type of natural resources are used, at what level of efficiency, and how use of one resource impacts others. For instance, how energy use or food production affects land, water, and air.

Knowledge has a unique place at the nexus of natural, human, and social capital, and this is where TNT research is focused. Building on past IIASA achievements which provided a systems perspective on technology innovation and change, TNT is a truly integrated program cutting across all other research areas at IIASA. This constitutes an important comparative advantage for conducting this research at IIASA. Another important advantage includes past achievements at IIASA to provide a systemic perspective on technology innovation, and change. This systemic research approach encompasses due consideration of: (i) sectorial context specificities; (ii) the commonality of technology characteristics such as interrelatedness, interdependence, and resulting inertia, or supply and demand interactions; and (iii) the main innovation and change levers (knowledge generation and diffusion) that apply across all sectors.

Main strengths and uniqueness

In terms of systems hierarchy, technological change arises from the spatial and temporal diffusion of individual innovations, all the way up to the emergence of new technological combinations. These latter could fundamentally redefine products, services, and even entire industries, markets, and human behavior. Technological interdependence and interrelatedness as well as 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 nor 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 empirical case studies, novel modeling approaches, as well as scenario studies and robustness analysis to inform technology policy choices

from a systemic perspective. For example, TNT modeling of the evolution of technological complexity has allowed the development of novel conceptual innovation systems frameworks and applied indicators, and new methods and historical data sets for comparing technological evolution across diverse technologies. These findings were applied in scenario development and validation.
TNT therefore has a unique and leading position in the study of technology systems and of systems thinking on innovation, which is widely recognized by the scientific community. This is reflected in the key positions held by TNT researchers within the IPCC, the Global Energy Assessment (GEA) and the SE4All initiative. The leading role of TNT in energy and climate-change related technologies will allow the program to extend concepts, models, and tools to the proposed new thematic focus on nexus technologies over the next five-year research cycle.

Key research questions and outlook

A key unifying strategic research question addressed by TNT research is what determines the rates of change of individual technologies and entire technology systems in response to the interplay of endogenous (e.g., innovation and market uncertainties) as well as policy (e.g., innovation push and demand pull) variables. Once an improved understanding of determinants of rates of change has been achieved, the focus can shift to identify viable options and policies for accelerated transitions towards sustainability. TNT will test these options and policies in models and scenario exercises using prototype, multi-actor, multi-sector models of the land-energy-water-air nexus, as well as the large-scale, sectorial, and integrated assessment models under development in other IIASA research programs.

In terms of research topics covered over the next five years, the program proposes to:

- Maintain its historical strength in the domains of energy and climate-related technology assessment and modeling. Extend the research to include diffusion and upscaling of some of the more critical technologies needed to achieve zero and even net-negative emissions.
- Extend conceptual frameworks, methods, and tools developed within the energy-climate field to the study of nexus technologies and systems, that is, key technologies that determine strong interactions between land, water, energy, and air. Study novel technology concepts that hold the potential to improve adverse spillovers by weakening these resource interactions.
- Develop concepts and methods to assess the relative impact of alternative determinants of rates of change across diverse technologies in the energy-climate and nexus technologies fields. Perform empirical meta-analyses in order to arrive at an integrated, quantitative theory of options and policies for accelerated transitions that can be translated into policy models.
- Extend TNT's pioneering, agent-based models of technology choice under uncertainty to include actor heterogeneity and interactions. Collaborate with other IIASA programs to translate acceleration options and policies into large-scale, sectorial, and integrated assessment models to analyze their impacts.

These four proposed research areas are further detailed below.

Maintain strength in energy-climate technologies. Two activities are planned in this research area. First, existing databases and research tools which serve the global scientific community will be maintained. Secondly, work on energy and climate technologies will include the extension of historical technology scaling data by economic and institutional variables, as well as an effort to quantitatively describe the evolution of the energy technology innovation system (where quantitative indicators are only available for the present) over the entire 20th century. This will allow a study of the growth dynamics of technology innovation systems in terms of their resource mobilization, actor networks, and reach, as well as underlying knowledge bases. This research aims at establishing a historical baseline for a comparable analysis of selected nexus technologies outside the energy-climate field as well as strengthening the energy-technology knowledge in cooperation with SE4All.

Nexus technologies. TNT will perform a technology assessment of nexus technologies. The initial focus will be on land-energy-water interactions, given that the impact on air (local and regional pollutants, greenhouse gas emissions) have been and continue to be studied by the Air Quality and Greenhouse Gases and Energy Programs. Examples of nexus technologies include: water reservoirs used for energy and/or irrigation, cooling towers, biofuels, and agricultural irrigation systems, among others. A range of options will be studied for each of these technologies, both extant and novel, low-impact systems, using frameworks, methods, and tools developed for the energy-climate realm to reveal similarities (but also differences). This work will include the Energy Technology Innovation System framework as well as the scaling analysis and diffusion modeling methods that have proved highly successful for technology inter-comparison and foresight analysis. This work will also feed into the Integrated Solutions for Water, Energy, and Land project, a partnership between Global Environment Facility (GEF), the UN Development Organization (UNIDO), and IIASA.

Determinants of rates of change. This research will include both theoretical-conceptual, and empirical (meta-analysis) components. First, a conceptual framework of the determinants of rates of change will be developed, differentiating between drivers relating to the technology itself (e.g., performance and costs, scale, and applicability) and drivers relating to the adoption environment (e.g., human capital, regulations, and financing constraints). Second, the conceptual framework will be tested using a quantitative meta-analysis of a larger sample of energy-climate and nexus technologies, drawing on past and ongoing TNT research. Depending on available external funding (a large-scale European Research Council proposal has been submitted and is under review) the sample of technologies for this meta-analysis may be significantly expanded to include behavioral “technologies”. The results of this analysis in turn will feed into the modeling and scenario development component described below.

Modeling technology choice and options of acceleration. TNT researchers will extend the program’s pioneering, agent-based models to include heterogeneous actors and adoption environments (e.g., human and social capital characteristics and incentive environments), and their interactions (e.g., social network effects, or strategic game theoretical actor interactions). The initial model extensions will focus on existing energy models and energy-climate models or those that are under development. However, after successful testing other nexus technologies will be considered as well. In collaboration with the Advanced Systems Analysis, Energy, Air Quality and Greenhouse Gases, and Ecosystems Services and Management Programs, the insights gained from TNT research will be tested in large-scale, sectorial, and integrated assessment models to explore the impacts of alternative scenarios of accelerated sustainability transitions and the effectiveness of alternative policies to achieve them.

Water Program (WAT)

NICHE: The urgent need to understand and address the complex and growing water challenges, together with the recognition that effective development solutions must bridge sectors and scales, calls for an interdisciplinary approach. The expertise in applied systems analysis offered by IIASA can provide just such an approach for the improvement of global water security. WAT can provide harmonization of data, methods and tools; consistency across sectors and scales; and continuity of outputs that are constantly maintained and updated.

OBJECTIVES:

- Develop an integrated nexus approach combining multi-model analysis across sectors and socioeconomic variables, including governance.
- Explore new water scenarios and solutions, based on cutting-edge global 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.
- Provide the analytical backbone for a comprehensive report on global water futures and solution options targeted at the World Water Forum in 2018.
- 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 consistency, and harmonizing databases on water-related issues.

EXPECTED IMPACT: Establishing a knowledge hub and global network for systems analysis approaches to the global water challenge. Communication and dissemination of multi-model, multi-sector, multi-scale analysis and contribution to capacity building and academic training world-wide. These activities should lead to a strong position within major international research projects (e.g., the Inter-Sectoral Impact Model Intercomparison Project) and strongly influence the science-policy dialogue of major international stakeholder conferences (e.g., the World Water Forum Rio 2018).

Objective and rationale

WAT aims to contribute to alleviating the world's water challenges by applying advanced systems analysis. The program will provide scientific evidence to support the identification and assessment of sets of robust strategies, technologies, and solution options, across sectors and scales. This work will enable science-based policy formulation and informed decision making in the face of the increasing uncertainty and growing complexity of today's water challenges. As a cross-cutting activity, WAT convenes international, interdisciplinary research on possible water futures and their implications across larger systems (the climate, water, food, energy, and ecosystem nexus) to help identify robust and sustainable options that can improve human wellbeing through enhanced water, energy, and food security.

With pressure on freshwater resources and ecosystems rapidly increasing, global leaders at Rio+20 acknowledged the core role of water to achieving sustainable development, stressing the need to take

decisive action today in order to sustainably meet development objectives. As over-abstraction becomes apparent in many regions of the world, water scarcity can become a constraint on energy production, industry, and agriculture, and its variability can be a risk to the interconnected supply chains needed for human and ecosystem health. For these reasons, the World Economic Forum has for many years listed water crises among its top global risks, and it was the number one risk in terms of impact in the 2015 report. Recognition of the importance of water for development has also led to the inclusion of a separate water goal— to ensure access to water and sanitation for all—in the UN Sustainable Development Goals (SDGs).

Yet, despite increasing awareness that water policy and management must be integrated across sectors and scales, integration of water research with other disciplines has lagged behind the progress made in other fields (e.g. integrated assessments such as the Intergovernmental Panel on Climate Change (IPCC) assessments and the Global Energy Assessment (GEA)). Up to date, comprehensive, and integrated global and regional assessments of water resources and water demand are needed. Furthermore, these should be built around a spatially detailed systems approach and involve multiple science partners, producing consistent messages for decision makers and stakeholders. In this way the work will help to identify options that work effectively across sectors and scales to improve human wellbeing through enhanced water, food, and energy security.

Methodological innovations are needed to: (i) link complex sectoral models operating at various spatial scales; (ii) incorporate knowledge of existing institutional and legal structures, their impacts and changes in institutional structure; (iii) assess the possibilities for and effectiveness of technological leapfrogging; (iv) incorporate water quality, groundwater balances, and the risk of saltwater intrusion; (v) assess development options and their consequences for different scales of management; (vi) and to facilitate the move from science to policy action.

Main strengths and uniqueness

Integrative systems analysis at IIASA allows advancements in water research through inclusive and interdisciplinary nexus analysis. As a result of the institute's experience in drivers of global change and multi-sector scenario building and evaluations, IIASA was a key contributor to the EU Framework Programme 6 projects Water and Global Change (WATCH), Scenarios for Europe and Neighbouring States (SCENES), and New Approaches to Adaptive Water Management under Uncertainty (NEWATER). These groundbreaking projects helped demonstrate the niche for a water research agenda at IIASA.

WATCH provided a first multi-model comparison and assessment of water resource availability with harmonized input datasets across global hydrologic models, land-surface models employed by general circulation models, and various vegetation models. NEWATER identified key elements of current water management regimes, investigated their interdependence, and identified transformational processes that could lead to more adaptive, integrated water management. SCENES worked with stakeholders and policymakers from river-basin to pan-European scales to build water scenarios for Europe, using a storyline and simulation approach to engage the stakeholders and capture their feedback. The LANDFLOW methodology, originally developed for tracking land extents along global supply chains from primary production to final consumption (land footprints), was extended for tracking key natural resources and proxies of environmental impacts and sustainable resource use. These could include irrigation water use (and its sustainability), deforestation, or land quality weighted indicators.

Global databases like the Special Report on Emissions Scenarios database, the Harmonized World Soil Database, and the Global Agro-Ecological Zones (GAEZ) data portal were also developed during this time and provided key information and inputs for these projects as well as many subsequent initiatives, such as ISI-MIP, led by the Potsdam Institute for Climate Impact Research and IIASA. The GEA, led by IIASA, also developed a wealth of information on energy balances, scenarios, and options, knowledge that is being applied for a better understanding of climate, land, and water futures.

WAT, is uniquely positioned for a number of research opportunities. First, undertaking coordinated perspective studies of water futures and the comparative analysis of integrated water solutions. Second, revisiting and improving transboundary water competition and management in large river basins. Third, fitting local water actions and policies into globally consistent and mutually beneficial development strategies.

Key research questions and outlook

The research strategy for the next five years involves advancing integration of tools and methods to improve water security, while also enhancing food, energy, and environmental security. Methodological innovations for integrated modeling will include better incorporation of institutional change; groundwater use and recharge; and incorporation of water quality modeling. Considerations of the required water quality for various uses; saltwater intrusion into coastal aquifers; and alternative water supply options such as desalination and water recycling and cascading will also be included in the analysis.

The focus of WAT in the past years has been on establishing a global network for systems analysis approaches to water challenges, and building a first set of comprehensive, cross-sectoral, stakeholder-informed scenarios for assessment of present and future water requirements and availability. In the future, scenarios will be refined feedback from stakeholders and incorporation of knowledge gained through case study analyses. The quantitative assessments of these scenarios will also be enhanced with improvements to databases and more integrative modeling methods, particularly with respect to location, water quality and demand, and the impacts of management options across sectors.

Information sharing across the global networks, and WAT's role as a knowledge hub, will be strengthened with greater capacity for online information exchange. However, WAT will shift toward developing the methods and tools to systematically include water resources and water demand in IIASA integrated modeling activities and to assess pathways to achieve sustainable water, energy, and food security. WAT's initiatives, such as the Integrated Solutions for Water, Energy, and Land project (IS-WEL), will contribute to this goal. Other key projects include WAT's work with the Risk and Resilience and Ecosystems Services and Management Programs on flood resilience; studies with private industries on joint fresh and saline groundwater management technologies; and collaborations with the UN Food and Agriculture Organization on GAEZ enhancements to strengthen decision support in applications and national projects. Collaborative projects with IIASA National Member Organizations on assessing and developing decision-support tools on land, water, and soil management techniques will also contribute to work to improve rural livelihoods and facilitate adaptation to climate change.

Additional case studies, particularly in Africa, will be sought to test the integrated frameworks in hot-spot regions and further develop the methods for cross-scale coherence of scenarios and solution options. The priorities and preferences of stakeholders in terms of the intervention options that they would most like to see assessed will be solicited. WAT will also use systems analysis to provide scoping of transition pathways to sustainability and water security, with adjustments made on the basis of stakeholder feedback and the incorporation of new knowledge.

In 2017 and 2018, the enhanced methods and tools will be used to uncover water solutions, that is, to assess portfolios of options (governance, structural and non-structural, technological, social), their costs and benefits, and the trade-offs and synergies across sectors and management scales. This will help identify those that can be effective, efficient, robust, and coherent. Tools will also be developed to communicate these possible solution pathways and to help visualize trade-offs and synergies. The analysis will provide the analytical backbone to producing a comprehensive report on global water futures and solution options and targeted at the World Water Forum in 2018.

Beyond 2018, integrated modeling and decision-support tools will continue to be improved in terms of accuracy, resolution, applicability at national scales and flexibility to deal with expanded sets of options and decision criteria, such as water quality enhancements, and enhanced assessment of the impact of various institutional and governance structures. Online global water databases and knowledge-sharing networks will receive continued support, documentation, and refinement through WAT activities.

World Population Program (POP)

NICHE: POP is the world's leading research group comprehensively studying the changing number and distribution and composition of humans on the planet and the effect of these changes for sustainable development. This is an essential complement to 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.

OBJECTIVES:

- Expand the multi-dimensional model of population dynamics developed at IIASA to include the urban/rural dimension for all countries.
- Define and test alternative specifications of Empowered Life Years (ELY), which is the number of years a person can be expected to be alive and to be "empowered" measured as health, ability to read, to be out of poverty, or in terms of 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 counties (the number is limited by data availability) going beyond the conventional simplistic indicators which only reflect chronological age.
- Provide policymakers with data pertaining to 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 future.
- Undertake science-policy dialogues on new measures of aging and the relationship to macro-economic impacts of demographic trends, e.g., retirement and pensions.

EXPECTED IMPACT: POP will make a major contribution in redirecting international discussions on population policy away from a narrow, Malthusian focus population growth alone, to a multi-dimensional perspective with explicit consideration of age-structures, place of residence, education, and health. This implies a fundamental change of the policy paradigm with people not primarily seen as a problem to be contained but rather as a resource for achieving sustainable development.

Objective and Rationale

POP directly and quantitatively addresses the changing number, distribution, and composition of humans on our planet. The program takes account of the fact that humans are the agents of change, and also considers how changes in the human population—in particular through health/mortality and migration—are being affected by changes in the human life support systems and other global trends. Finally, human wellbeing can serve as the main criterion for whether or not the global changes go into a desirable direction. This triple function of the study of the human populations—driving change, being affected by change, and serving as a sustainability criterion—puts this research agenda right at the heart of the IIASA mission.

POP research is firmly based in formal demography and, in particular, in the methods of multi-dimensional population dynamics that were developed at IIASA during the 1970s and early 1980s. These methods allow population analysis and projections to go beyond the conventional focus on age

and sex structures alone and quantitatively address other important demographic dimensions such as level of educational attainment, health status, place of residence, labor force participation, and others. This multi-dimensional approach helps to add the "quality dimension" to conventional analysis of population numbers. While changes in population size clearly matter when it comes to meeting human needs under a human rights perspective, the capabilities of human populations to meet those needs for themselves and for others greatly depends on their education and health and, hence, economic productivity and the building of good institutions. In this sense, the quality dimension of human population matters greatly for both the mitigative and adaptive capacity of societies to climate change, and is a key determinant of sustainable development in general.

POP has a truly global focus. Even in specific national or sub-national case studies the aim is to discover universal aspects of the determinants and consequences of population trends and, in particular, the nature of population-development-environment interactions. In addition to basic research on these topics, POP is deeply involved in discussing the foundations of international, population-related policies with stakeholders at all levels.

Main strengths and uniqueness

POP, together with its partners in the Wittgenstein Centre for Demography and Global Human Capital (the Vienna Institute of Demography of the Austrian Academy of Sciences and the WU – Vienna University of Economics and Business), is arguably the world's leading center for multi-dimensional demographic analysis and its applications. It has built on the fact that IIASA was the cradle of these methods and expanded the scope of their applications, which initially focused on regional and spatial dimensions. Using these methods to model population dynamics by age, sex, and different levels of educational attainment, the program has advanced the scientific frontier in reconstructing and projecting human capital. In 2011, *Science* published a major review article "Global Human Capital: Integrating Education and Population" dedicated entirely to this new approach. More recently it was applied to calculating alternative population and human capital scenarios for all countries in the world.

POP was also the global leader in recent work on redefining the concepts of age and population aging. While population aging has developed into a major concern, not only for industrialized countries but also emerging economies with low fertility like China, the indicators on which analyses have been based are typically too simple. Proportions of the population above a certain age threshold, such as 60 or 65, have mostly been studied to approximate economic and other dependencies. However, since life expectancy continues to improve substantially and this is also associated with improving health status and delayed cognitive decline, one can be justified in saying "70 is the new 60" or "80 is the new 70". POP has taken the lead in adjusting the concept of dependency through developing concepts such as prospective age and estimating new measures of age and aging for many countries around the world. The recently introduced "characteristic approach" to the study of population aging generalizes previous approaches and takes into account multiple features of population aging.

These multi-dimensional perspectives on population dynamics go beyond the conventional focus on chronological age and sex, and have been further conceptualized under the "Theory of Demographic Metabolism." This theory is based on the idea that societies change to a large extent through the replacement of generations and is one of the few theories of social change with predictive power. It is not only relevant for social and economic forecasting but also for studying future interactions of human populations with the natural environment. It has been the theoretical foundation for

producing the “human core” of the Shared Socioeconomic Pathways. Building on a long tradition of population-environment work at IIASA, POP has also become the world’s leading demographic group that works closely with the international research community on global environmental change.

Key research questions and outlook

Over the coming years POP will further strengthen its research in the two fields where it is currently a global leader, namely the modeling and projection of human capital and the redefinition of age and aging. On the latter topic different characteristics that are relevant to population aging will be studied using existing information as well as new data obtained through a collaborative EU project. POP will also study what influences peoples’ subjective age—how old they feel—and how this translates into a willingness to retire at a later stage. This information will be taken into account in population projections performed for a number of countries.

In terms of human capital projections, the work that so far has been largely limited to the national level will be extended to include urban/rural differences and the spatial dimension more generally. While over the past year the work has focused primarily on capturing the social heterogeneity of populations, POP will now try to add the spatial dimension to it. This is because for interactions with economic development and the environment it matters both who people are (social) and where they are (spatial). This approach requires further methodological research to appropriately combine these different forms of heterogeneity.

Another planned line of research will apply the concept of demographic metabolism to modeling the changing composition of populations with respect to their attitudes and behaviors regarding climate change and the environment in general. While it is widely accepted that transitions to sustainability require fundamental changes in behavior, there is very little quantitative analysis to date on how these new behavioral modes would develop over time and how the behavior of a pioneering group would subsequently spread among the general population. In particular, one would expect changes along cohort lines, that is, new generations behaving differently. Here, POP hopes to advance methodological approaches and their empirical applications.

Finally, POP plans to conduct systematic research on population-based measures of human wellbeing that also lend themselves to the use as general sustainability criteria. Since individual survival is a basic prerequisite for enjoying any wellbeing and quality of life, these indicators will likely be based on life expectancy. However, since pure survival is usually not considered to be enough, we will work on indicators of ELY such as health life expectancy, literate life expectancy, or out-of-poverty life expectancy. Such indicators can then become the dependent variable in systems models that try to comprehensively capture the “production” of human wellbeing.

New Research Areas

To enable IIASA to meet its mission and strategic objectives over the next five years it will be necessary to develop new core competencies in research areas likely to play a major role in the current global transformation agenda. These new research areas will contribute to and complement the institute's existing portfolio and enable greater impact globally. The exact organizational form these will take is yet to be decided.

Global Health

Several IIASA programs deal with global changes that have direct or indirect implications on human health. This ranges from the effects of indoor and outdoor air pollution on health and life expectancy to the effects of food supply and diet, to global changes in the dynamics of infectious diseases, to natural disasters, and to the impact of population aging. There is also broad consensus that possible adverse effects on human health are one of the main reasons for our concerns about unsustainable trends in many domains. Yet, at present, there is insufficient credible in-house competence in global health or epidemiology (with a good knowledge of the relevant bio-medical literature) that can link this important IIASA research to the state of the art in the international global health research community.

Health figures are very prominent in international global change discussions and several of the new Sustainable Development Goals (SDGs) deal directly or indirectly with human health. In an effort to strengthen IIASA involvement in this research community the institute could build on already existing contacts to some of the leading centers in the field that can partner with IIASA in the study of global health, such as the Global Burden of Disease Study (WHO and Institute for Health Metrics and Evaluation, University of Washington, the Harvard School of Public Health the Karolinska Institute's Department of Epidemiology and Public Health Sciences, the Australian National University's National Center for Epidemiology and Population Health, the University of Cape Town's School of Public Health and Family Medicine, the London School of Hygiene and Tropical Medicine, and the Erasmus University's Department of Public Health, among others.

Importantly, at this stage, it is not intended to develop capability in traditional health sciences, but rather to build integrative expertise and competence in health areas that complement existing or future IIASA research.

Exploratory projects and emerging opportunities

In addition to its integrated and cross-cutting research activities, IIASA will continue to enhance its capability to anticipate and cope with rapid changes and new crises and opportunities. The emphasis will be on paradigm-changing transformations, from the global to the sector and place-specific, and from the medium-term to the very long term. Much of this research will examine unusual events, surprises, and extreme values of distributions, rather than averages or normally distributed phenomena. This research will be conducted as individual, mostly short-duration projects, lasting from a few months to a year. The projects will typically be feasibility studies encompassing exploratory in-house research and workshops.

New methodologies in systems approaches

The IIASA Systems Analysis Forum (SAF) will facilitate and catalyze methodological research at IIASA.

Applied systems analyses build on mathematical models and computational techniques for describing and analyzing complex systems. It is increasingly recognized that accelerating global transformations and rising levels of global interconnectedness necessitate novel methods for identifying scientifically sound options for policy advice. Methodological advances are also needed for innovating the interdisciplinary and integrated perspectives that lie at the core of the IIASA research agenda. Among the many challenges requiring radically new approaches are decentralized decision-making and bounded rationality; compounding uncertainties and systemic risks; nonlinearities and regime shifts; social interactions and collective phenomena; spatial hierarchies and network dynamics; synergisms and antagonisms across multiple objectives; as well as scientific visualization and communication, to name just a few.

IIASA leadership in the systems analysis of global and universal problems will be extended based on methodological innovations inspired by, and co-developed with, applied research activities at IIASA. Since all IIASA programs develop methods and tools in different ways, the SAF platform will help to consolidate and support these activities and thereby optimize the cross-fertilization of methodological and applied research at IIASA. In addition, dedicated SAF activities will promote exchanges among IIASA researchers and methodological experts around the world, accelerating knowledge transfer and methodological inspiration.

Co-led by the Advanced Systems Analysis and Evolution and Ecology Programs, the SAF will pursue these objectives by building synergies between in-house capacities, world-leading experts, and IIASA member countries. Specific activities include:

- Following the success of the Systems Analysis 2015 conference, regular conferences will be organized to attract world leaders in systems-analysis methodology to discuss challenges and opportunities in the context of IIASA research.
- Organizing a systems-analysis course or school will be considered.
- Regular internal calls for proposals for exploratory, methodologically oriented, small-scale projects will be issued.
- Methodological innovators from around the world will be invited for presentations and discussions.
- Targeting researchers in countries with IIASA membership, by running workshops or schools on systems-analysis methods, models, and tools will be considered.

Science to policy and foresight

IIASA was founded on the dual principles of undertaking world-class science and translating that science into policy options for decision makers. The IIASA membership structure and resulting National Member Organizations (NMOs), provide a unique mechanism, and comparative advantage, for IIASA to access major policymakers in its member countries and beyond. The result is that IIASA has an unprecedented track record of providing objective, science-based policy input to all the major policy challenges, globally, regionally, and nationally. For example, IIASA, in direct collaboration with stakeholders and policymakers, has a major role in: (i) international policy on climate (e.g., through

the Intergovernmental Panel on Climate Change, energy (e.g., through the UN Sustainable Energy for All initiative) and sustainable development (e.g., through the UN Sustainable Development Solutions Network); (ii) regional policy on clean air and pollution mitigation (e.g., through the European Commission Clean Air Policies and various national policies, such as the German Advisory Council on Global Change, the Finnish Ministry of Employment and the Economy, and various REDD+ partnerships). The IIASA flagship models—the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), Global Biosphere Management Model (GLOBIOM) and Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model—are used extensively by national government policymakers throughout the world. Building on these science to policy successes, IIASA, in partnership with the Joint Research Centre of the European Commission, has launched an annual Summer School on Evidence and Policy, bringing together researchers and policymakers from around the world to learn how to optimize the use of scientific evidence in policy making.

To date, the majority of these highly successful science to policy interactions have been undertaken by individual research programs and initiatives and this will continue into the future, as providing scientifically-robust policy options to decisions makers is an integral component of the IIASA systems approach. All of the institute's new and existing large-scale, integrated projects, including the Futures Initiatives, involve key policymakers and stakeholders as active project partners. In addition, IIASA programs have both expertise and experience in conducting prospective modeling and both quantitative and qualitative scenario development. However, there is considerable potential for IIASA to further foster relationships and dialogue between researchers and policymakers by developing and building greater Institute-wide capabilities in these areas.

To enhance and streamline this process, IIASA will establish (with new expertise as required) a small, dedicated science-policy and foresight team to work both within and across programs and with member country policymakers and institutions. This will enhance IIASA capacity to co-design research initiatives that aim to have policy impact, and increase application of the institute's methods and results to decision making processes. While IIASA will maintain its focus on modeling and analysis at the global level and on universal challenges, it will work closely with partners to translate the global frameworks, scenarios, models, and data into the regional and national context. This will transform the global analysis into nationally relevant decision-support modeling and analysis. In return, NMOs will provide valuable data, national policy perspectives, and nationally developed models. These research partners can also provide the link between IIASA researchers and national decision makers to create more effective and enduring policy dialogue partnerships.

Capacity development and training

Capacity development and training at IIASA is an integral part of the institute's research, and its mission to ensure that IIASA analyses and systems approaches inform solutions to the world's challenges. The institute's most visible capacity development activities have been the Young Scientists Summer Program (YSSP), the Southern African YSSP, and Postdoctoral Program. However, IIASA research programs have also conducted targeted training in IIASA methods as elements of research collaborations or in partnership with National Member Organizations (NMOs) efforts to build national capacities in systems analysis. The increase in number and diversity of IIASA NMOs and the countries they represent, as well as the growing interest in IIASA approaches to the complex, interconnected challenges facing the world, demands a new strategy to expand the institute's training capabilities.

This strategy will comprise three elements (Table 1):

- Consolidate and enhance existing activities at the institute.
- Develop and strengthen member country and regional partnerships that combine research goals with training elements, and increase awareness of IIASA work.
- Build formal and informal cooperative networks that enhance scientific goals and extend the reach of IIASA methods.

The YSSP will remain the cornerstone of IIASA training activities, with some program revisions to reflect evolving institution priorities. The Postdoctoral Program, which began in 2006, will continue to grow and expand cooperation with funding agencies and foundations in member countries. This will both enhance IIASA research and offer new opportunities for cooperation with member country scientists.

A new emphasis on capacity development will build on the interest shown by member countries in applying IIASA systems approaches to national and regional challenges. IIASA will explore and increase opportunities for capacity development in the context of research collaborations and existing academic affiliations, creating a framework for supporting formal and informal training and exploring opportunities to make training more widely available.

Capacity development activities will be tailored to national and IIASA program interests, and may include partnerships with academic institutions, professional societies, international organizations, and government agencies. It will include exchanges of researchers between IIASA and national institutions, through initiatives such as the recently inaugurated Asian Demographic Institute in Shanghai and the anticipated Southern African Systems Analysis Centre, or through proposed institutional network-building mechanisms such as the International School of Excellence and the IIASA External Faculty. Efforts could expand to include accreditation of IIASA-led systems analysis courses through such partnerships.

Training the next generation of scientists is an area of particular interest for private funders and international development agencies, as well as research funding agencies. The capacity development and training strategy will include working with NMOs and the IIASA Development Office to explore opportunities for support from national and multilateral aid agencies that are searching for new approaches to complex issues. The institute will also seek funding from private foundations that share the IIASA goals of broadening the use of systems approaches to solving the problems caused by a rapidly changing world.

Table 1. Elements of IIASA capacity development and training strategy

IIASA Activities	NMO & Regional Partnerships	Institutional Global Initiatives & Cooperation
YSSP: more IIASA-wide focus, alumni follow-up *Postdocs:* cross-cut topics, targeted outreach *Systems Analysis Training:* discrete modules in methodology & approaches *Young Scholars Community Building:* in-house activities	*Postdoctoral cooperation:* NMO-IIASA postdoc programs *Partnerships with member country institutions:* "sandwich" training, joint appointments, exchanges, e.g., Asian Demographic Institute, Southern African Systems Analysis Centre, Asian Demographic Institute *Joint courses and training* *Regional collaborations (tropics, Arctic)*: methods, decision support	*International School of Excellence:* global network of early-career scientists collaborating on IIASA-driven initiative *IIASA External Faculty:* Formalization of global collaboration network *Capacity Development Partnerships:* enhance IIASA capabilities and explore new areas through cooperation, e.g., Moscow Summer Academy on economic growth and governance of natural resources, JRC-IIASA Summer School on Evidence and Policy, etc.

Appendix 1: Timeline of Selected IIASA Achievements 1972-2015 (with focus on last five years)

1972	At the height of the Cold War, 12 nations from the East and West meet in London to sign the charter establishing IIASA in the neutral setting of Austria.
1974	George Dantzig, winner of the US National Medal of Science, is joined at IIASA by Nobel Prize laureates Tjalling Koopmans (USA) and Leonid Kantorovich (USSR) to expand IIASA research into advanced systems science and methodology.
1975	A new research field, Adaptive Ecosystem Policy and Management, is founded at IIASA based on results of a study relating forest conditions to pest propagation that has implications for forest management policy throughout North America and Scandinavia.
1976	IIASA scientists warn the world about the dangers of climate change and suggest pioneering solutions such as capturing and storing carbon. IIASA was one of only two institutions worldwide that, by the mid-1970s, already had an established research program on climate change and policy.
1977	The first Young Scientists Summer Program is a huge success and during the next 38 years IIASA attracts over 1,700 talented young scientists to spend a summer working with scholars from other nations and disciplines. Many will go on to take senior posts in academia, business, and government.
1980	A chance conversation between IIASA colleagues brings unexpected results. James Vaupel, a US demographer, mentions a scientific problem to Soviet mathematician, Anatoli Yashin. “I think I can help,” Yashin replies. The two go on to develop more reliable projections of population aging in developed countries.
1981	IIASA publishes the first comprehensive, truly global assessments of energy issues, resulting in the internationally acclaimed report, Energy in a Finite World.
1982	An IIASA research team of chemists, biologists, mathematicians, engineers, hydrologists, economists, computer specialists, and managers completes a study on eutrophication and management of Lake Balaton, central Europe’s largest lake. Its findings influence water policy in Italy, Japan, the USA, and the USSR.
1983	Groundbreaking research by an IIASA scholar provides the intellectual underpinnings for the later US Department of Justice’s antitrust case against Microsoft. The findings pioneered the modern approach to increasing returns which shows how powerful firms can exploit the particular nature of high-tech markets to the disadvantage of opponents who offer better products.
1986	IIASA scholars publish Sustainable Development of the Biosphere, which is quickly accepted by the science community as the core scientific text on sustainable development.

1988	In response to mounting tensions regarding global food issues, IIASA creates an unprecedented computer model that links national agricultural models. Named the Basic Linked System, it becomes a practical tool for determining the effectiveness of policies to eliminate hunger and the impacts of agricultural trade liberalization.
1989	The IIASA model of Europe's acid rain problem is officially adopted by the 28 countries of the Geneva Convention on Transboundary Air Pollution as the main technical support for renegotiation of the treaty. This is the first time that all parties to a major international treaty agree to accept a single scientific model.
1991	IIASA researchers complete the first consistent continent-wide assessment of forest resources in Europe and the European regions of the former Soviet Union, revealing alarming consequences of air pollution for European forests.
1994	The IIASA Regional Acidification Information and Simulation (RAINS) model underpins the agreement of 33 European governments to reduce damaging emissions of sulfur dioxide. The following year, the RAINS model is extended to facilitate the analysis of sulfur dioxide pollution in Asia and is presented to energy planners and government officials in 18 Southeast Asian nations.
1995	Five IIASA scientists are chosen to be Lead Authors of the Second Assessment Report of the Intergovernmental Panel on Climate Change. Since then, over twenty IIASA scholars have played leading roles in the IPCC's third, fourth, and fifth assessment reports, which provide the world with the most scientifically advanced, comprehensive, and rigorous analysis of the state of climate change.
1996	A second edition of the IIASA book The Future Population of the World: What Can We Assume Today? is published. It includes the first-ever probabilistic population scenarios (predicting world population will probably never double again) and new findings on population aging.
1998	The World Energy Council partners with IIASA in a unique study on Global Energy Perspectives. This analyzes how current and near-term energy decisions will have long-lasting implications throughout the twenty-first century. The findings of the five-year study are presented at the World Energy Congress in 1995 and 1998, and the results published in a Cambridge University Press book in 1998.
2000	IIASA scientists and models play a leading role in preparing the most comprehensive and sophisticated scenarios yet of greenhouse gas emissions for the twenty-first century. The work is published as the Special Report on Emissions Scenarios by the Intergovernmental Panel on Climate Change and Cambridge University Press in 2000.
2001	IIASA demographers are first to forecast, in a Nature article, that the world population will peak in the twenty-first century and then begin to decline.
2002	IIASA scientists complete the most comprehensive study of Russian forests and land resources ever undertaken. Results are presented to President Putin of Russia.

2002	A UN-commissioned IIASA report, presented to the World Summit on Sustainable Development in Johannesburg, highlights the need to focus on extending the mitigation scope of the Kyoto Protocol and put the issue of adaptation to climate change on the global agenda of international negotiations.
2004	IIASA scientists reveal that undesirable genetic changes are taking place in fish stocks as a result of commercial exploitation. Documentation of these evolutionary changes could have provided a valuable early warning signal of the collapse of a fish stock such as the northern cod in the early 1990s.
2005	Disaster aid is often too little and too late. It also discourages governments and individuals from taking advantage of the high returns to preventive action. In a *Science* article, scholars from the IIASA Risk, Modeling and Society Program identified several innovative approaches to free vulnerable countries from dependence on unpredictable post--disaster assistance.
2007	IIASA scientists share the Nobel Peace Prize with authors of the IPCC reports and Al Gore for "their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change." They follow in the footsteps of four Nobel Prize laureates who have worked at IIASA: Tjalling Koopmans and Leonid Kantorovich (Economics, 1975); Paul Crutzen (Chemistry, 1995); and Thomas Schelling (Economics, 2005).
2011	IIASA co-develops and hosts the Representative Concentration Pathways database that equips the climate change research community with common greenhouse gas emission data.
2011	IIASA works with the International Council for the Exploration of the Sea to develop a framework that provides the building blocks fisheries managers need to conduct evolutionary impact assessments for the fish populations they oversee.
2012	IIASA publishes the Global Energy Assessment, the first ever fully integrated assessment of this kind that goes on to provide the scientific basis and key objectives for the United Nations Secretary-General's Sustainable Energy For All initiative.
2012	IIASA and partners identify 14 measures to reduce short-lived climate forcers (SLCFs) which provides the scientific evidence for the Climate and Clean Air Coalition that today includes nearly 100 countries and non-state partners.
2012	IIASA, the Potsdam Institute for Climate Impact Research, and others launch the Inter-Sectoral Impact Model Intercomparison Project to bring together all the major climate impact modeling groups, allowing them to compare their work and results.
2012	IIASA establishes the REDD Policy Assessment Centre which goes on to become an important global forum for sharing data on forests and deforestation drivers, and developing reference methods and best practices for land-use planning.

2012	IIASA creates the Energy Technology Innovation Systems framework which integrates innovation drivers and policies across all stages of technology development and all elements of energy systems. The framework goes on to reveal important insights into how to stimulate innovation in the energy sector.
2012	IIASA begins working to develop new ways of understanding population aging including a new approach to quantify age in terms of the number of years a person has left to live.
2012	IIASA launches its first regional Young Scientists Summer Program with partners in South Africa. Over the following three years, over 80 doctoral students take part.
2012	IIASA 40th Anniversary Conference examines the challenges facing humanity on the road to sustainability.
2013	IIASA brings together 40 leading institutions to launch the Water Futures and Solutions Initiative to identify options for improving water security that work consistently across scales and sectors.
2013	The European Commission introduces a new clean air policy package to reduce pollution, based on scenarios developed by the IIASA GAINS model. The new policies are projected to avoid 58,000 premature deaths, save 123,000 km^2 of land from nitrogen pollution, and protect 19,000 km^2 of forest from acidification by 2030.
2013	IIASA and partners launch a revamped Geo-Wiki to harness the power of citizen science to collect and verify land-cover data, and thereby dramatically improve the quality of the data.
2013	IIASA conducts the most comprehensive assessment to date of global livestock production and its role in land use and contribution to climate change.
2013	IIASA, private sector representatives, and policymakers establish the Zurich Flood Resilience Alliance to strengthen the resilience of communities against floods.
2013	Analysis from the IIASA catastrophe simulation model informs the rationale for the Loss and Damage Mechanism of the UN Framework Convention on Climate Change.
2013	IIASA develops more sophisticated methods of optimization for economic models and brings this together with other models that integrate resource and environmental constraints in a new book, Green Growth and Sustainable Development.
2013	IIASA and European Forum Alpbach launch the Alpbach-Laxenburg Group. Bringing together leading minds from academia, government, business, civil society, and the arts, to address the challenges facing humanity.
2014	The Intergovernmental Panel on Climate Change publishes its Fifth Assessment Report—the most authoritative source of information on climate change to date. Twenty-one IIASA researchers and council members were lead authors or contributors.

2014	The European Commission agree a proposal for new climate and energy targets for 2030, including a reduction of EU greenhouse gas emissions by 40% below the 1990 level. Negotiations leading to the compromise were informed by an extensive impact assessment to which IIASA researchers contributed data and results from the GAINS model on the benefits and costs of various climate policies.
2014	IIASA launches the latest version of its Global Agro-ecological Zones model system, which the Food and Agriculture Organization of UN is using to help shape countries' land-use policies.
2014	IIASA publishes the first population projections for all countries of the world that include people's level of educational attainment. The projections are also based on the broadest ever synthesis of expert knowledge on drivers of fertility, mortality, migration, and education in all parts of the world.
2014	A IIASA study shows how expanding access to household electricity services accounts for only a small portion of total emission growth, shedding light on an ongoing debate on potential conflicts between climate and development.
2014	IIASA develops a stochastic version of its Global Biosphere Management Model (GLOBIOM) to take into account uncertainties and shocks as it analyzes competition for land between agriculture, bioenergy, and forestry systems.
2014	Ongoing development of new methods to explore the equitable governance of common goods results in the first study to examine the optimal institutional strategy to induce cooperation when rewarding and punishing are both possible.
2015	IIASA extends the database of Shared Socioeconomic Pathways (SSPs) that it hosts for the Intergovernmental Panel on Climate Change. The SSPs provide data on five alternative future worlds which vary with respect to social and economic mitigation and adaptation challenges.
2015	A new post-doctoral fellowship begins in honor of former IIASA Director Peter E de Jánosi following a successful fundraising campaign of one million dollars.
2015	IIASA and partners launch two new projects—The World in 2050, and Integrated Solutions for Water, Energy, and Land —to analyze the interconnected issues of sustainable development and identify integrated solutions.
2015	IIASA hosts the first in a series of international conferences to explore the current and future directions of systems analysis.

IIASA Members

IIASA is an international, independent, interdisciplinary research institution with over forty years' experience in global change research. IIASA is represented by its National Member Organizations (NMOs). On 31 December 2015 these were:

AUSTRALIA The Commonwealth Scientific and Industrial Research Organisation (CSIRO)
AUSTRIA The Austrian Academy of Sciences (OEAW)
BRAZIL The Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES)
CHINA National Natural Science Foundation of China (NSFC)
EGYPT Academy of Scientific Research and Technology (ASRT)
FINLAND The Finnish Committee for IIASA
GERMANY Association for the Advancement of IIASA
INDIA Technology Information, Forecasting and Assessment Council (TIFAC)
INDONESIA Indonesian National Committee for IIASA
JAPAN The Japan Committee for IIASA
KOREA, REPUBLIC OF National Research Foundation of Korea (NRF)
MALAYSIA Academy of Sciences Malaysia (ASM)
MEXICO Mexican National Committee for IIASA
NETHERLANDS Netherlands Organization for Scientific Research (NWO)
NORWAY The Research Council of Norway (RCN)
PAKISTAN Pakistan Academy of Sciences
RUSSIA Russian Academy of Sciences (RAS)
SOUTH AFRICA National Research Foundation (NRF)
SWEDEN The Swedish Research Council for Environment,Agricultural Sciences and Spatial Planning (FORMAS)
UKRAINE Ukrainian Academy of Sciences
UNITED KINGDOM Research Councils of the UK
UNITED STATES OF AMERICA The National Academy of Sciences (NAS)
VIETNAM Vietnam Academy of Science and Technology (VAST)

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