International Institute for
Applied Systems Analysis
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SYSTEMS ANALYSIS FOR SUSTAINABLE WELLBEING

50 years of IIASA research, 40 years after the Brundtland Commission,
contributing to the post-2030 Global Agenda

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FOREWORD

Half a century ago, an ambitious transnational effort led to the establishment of the International Institute for Applied Systems Analysis (IIASA), with Austria as its proud host. At that time, the objective of IIASA was to bring the best scientists from across the East-West geopolitical divide to address the pressing global challenges of that time in the most comprehensive way possible using the most advanced scientific methods available then.

As this IIASA Flagship Report impressively documents, over the past 50 years, IIASA has transformed into a truly global institute that has spearheaded scientific analysis, modeling and scenario-based assessments in the many fields that jointly underpin sustainable development. And today, as the global 2030 Agenda enters its mid-term review, this report also offers important science-based contributions to thinking about policy priorities for our common future.

Several of the major global science-based assessment processes that shape our discussions about sustainable development today actually started in and around IIASA. In the 1970s, a series of workshops organized by IIASA on anthropogenic climate change, fed into the first World Conference on Climate Change and subsequently into the Intergovernmental Panel on Climate Change (IPCC), with several key individuals in this process having worked at IIASA. A 1986 IIASA Report on the "Sustainable Development of the Biosphere" conceptualized this influential notion before it was popularized through the Brundtland Commission Report. In several other fields of global development IIASA has made influential contributions. These range from advancing demographic analysis to include human capital and specifically women's education, to assessing technologically feasible pathways to limit global warming to 1.5°C above pre-industrial levels, and evaluating health impacts of air pollution, water systems and clean energy, to name just a few.

In this report IIASA researchers highlight the desirability to focus on the overarching goal of “sustainable wellbeing” in addition to the many more specific Sustainable Development Goals and targets.

The very existence of IIASA gives rise to hope for the future. It was established as a collaboration among leading scientists from the East and West at the height of the Cold War to focus on common challenges facing all of humanity. It continues today with scientists from all over the world and many different disciplines brought together by the joint aspiration to develop and apply the best available scientific tools to systemically understand the big challenges we face today and advance solutions to support humanity’s efforts to achieve sustainable wellbeing for all.

Let me take this opportunity to congratulate IIASA for a half century of important achievements and wish it all the best for an equally successful and productive future. As the host country of this important international institution, Austria will do everything to support its efforts to bring the power of science to bear on the challenges of global sustainable development.


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Alexander Van der Bellen
Federal President,
Republic of Austria

PREFACE

Michael Clegg
Chair of IIASA Council

Albert van Jaarsveld
Director General

The International Institute for Applied Systems Analysis (IIASA), established at the height of the Cold War in 1972, embodies science diplomacy in several dimensions. Contributing to over five decades of work on pressing global issues with member organizations from around the world, it serves as a neutral meeting place for scientists and policymakers from different political systems, ideologies, cultures, and disciplines. Through its research programs and initiatives, the institute applies cutting edge scientific methods to address some of the most difficult challenges humanity faces. Those working at IIASA find common ground in the universal language of science and the powerful tools of systems analysis. Based on a combination of its international credibility, neutrality, and the application of an integrated systems approach, IIASA offers unique assistance in building bridges between countries and stakeholders in the pursuit of sustainable development and in informing international negotiations on global change. In addition, IIASA has been training generations of scholars in the skills needed to navigate international science–policy interfaces.

There is a very broad spectrum of scientific disciplines represented at IIASA with an emphasis on both the socioeconomic and environmental aspects of global change as well as issues of equity and governance. With a comprehensive analytical toolkit, the institute is well positioned to inform the global transition to sustainable development. In its current research strategy 2021–2030, IIASA is organized into six major research programs. The programs on Advancing Systems Analysis, Biodiversity and Natural Resources, Energy, Climate and Environment and Population and Just Societies all build on important research traditions at IIASA.

The program on Economic Frontiers is a new addition, while the Strategic Initiatives Program, a further innovation, is responsive to bottom-up proposals by IIASA staff and our National and Regional Member Organizations with respect to prioritizing cross-cutting studies of high policy relevance.

As IIASA enters its sixth decade, new global challenges are arising, while existing challenges are unfolding in more dramatic ways than anticipated earlier—dramatic losses in biodiversity, the fact that efforts to mitigate against climate change are falling far behind internationally agreed targets, the looming threat of new pandemics driven by emerging pathogens, the reemergence of the serious risk of famines, and failure to meet agreed education and other sustainable development goals—in all these cases, the problems are interconnected, requiring a comprehensive systems analysis approach to understand potential synergies, feedbacks, and avoid unintended secondary consequences. For these reasons, the work of IIASA, with its international status and systems science approach, is more crucial today than ever before. Moreover, the science diplomacy character of IIASA, which uses science to promote cooperation between differing communities on matters of common interest, amplifies the global value of the institute.

We hope that the readers of this IIASA Flagship Report will gain an insight into the considerable past contributions of the institute and share with us the excitement offered by its future endeavors, namely to advance integrated systems science to meet the challenges of sustainable development and, ultimately, to help ensure sustainable wellbeing for all.


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Wolfgang Lutz
Interim Deputy Director General for Science, Co-editor of the Report


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Shonali Pachauri
Research Group Leader and Principal Research Scholar, Co-editor of the Report

LIST OF AUTHORS AND CONTRIBUTORS

Guy Abel, Research Group Leader at the Asian Demographic Research Institute; Professor at Shanghai University; Research Scholar at Migration and Sustainable Development Research Group, Population and Just Societies Program, IIASA

Marina Andrijevic, Research Scholar at Transformative Institutional and Social Solutions Research Group and Integrated Assessment and Climate Change Research Group, Energy, Climate, and Environment Program, IIASA

Andrey Lessa Derci Augustynczik, Research Scholar at Integrated Biosphere Futures Research Group, Biodiversity and Natural Resources Program, IIASA

Juraj Balkovič, Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program, IIASA

Jutta Beher, Research Scholar at Biodiversity, Ecology and Conservation Research Group, Biodiversity and Natural Resources Program, IIASA

Esther Boere, Research Scholar at Integrated Biosphere Futures Research Group, Biodiversity and Natural Resources Program, IIASA; Assistant Professor at Institute for Environmental Studies, Vrije Universiteit Amsterdam

Benigna Boza-Kiss, Research Scholar at Transformative Institutional and Social Solutions Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Elina Brutschin, Research Scholar at Transformative Institutional and Social Solutions Research Group, Energy, Climate, and Environment Program, IIASA

Edward Byers, Senior Research Scholar at Integrated Assessment and Climate Change Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Shelby Corning, Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program, IIASA

Sibel Eker, Research Scholar at Sustainable Service Systems Research Group, Energy, Climate, and Environment, IIASA; Assistant Professor at Radboud University

Brian Fath, Principal Research Scholar at Systemic Risk and Resilience Research Group, Advancing Systems Analysis Program, IIASA; Professor at Towson University

Günther Fischer, Distinguished Emeritus Research Scholar at Water Security Research Group, Biodiversity and Natural Resources Program, IIASA

Christian Folbert, Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program, IIASA

Stefan Frank, Senior Research Scholar at Integrated Biosphere Futures Research Group, Biodiversity and Natural Resources Program, IIASA

Oskar Franklin, Senior Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program, IIASA

Oliver Fricko, Research Scholar at Integrated Assessment and Climate Change Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Matthew Gidden, Senior Research Scholar at Integrated Assessment and Climate Change Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Adriana Gómez-Sanabria, Research Scholar at Pollution Management Research Group, Energy, Climate, and Environment Program, IIASA

Anne Goujon, Program Director and Principal Research Scholar at Population and Just Societies Program, IIASA

Arnulf Grubler, Distinguished Emeritus Research Scholar at Energy, Climate, and Environment Program, IIASA

Petr Havlík, Program Director and Principal Research Scholar at Biodiversity and Natural Resources Program, IIASA

Florian Hofhansl, Research Scholar at Biodiversity, Ecology and Conservation Research Group, Biodiversity and Natural Resources Program, IIASA

Lena Höglund Isaksson, Senior Research Scholar at Pollution Management Research Group, Energy, Climate, and Environment Program, IIASA

Daniel Huppmann, Senior Research Scholar at Integrated Assessment and Climate Change Research Group, Energy, Climate, and Environment Program, IIASA

Jill Jäger, Independent Scholar; Former Deputy Director (1994-1998), IIASA

Martin Jung, Research Scholar at Biodiversity, Ecology and Conservation Research Group, Biodiversity and Natural Resources Program, IIASA

Taher Kahil, Research Group Leader at Water Security Research Group, Biodiversity and Natural Resources Program, IIASA

Gregor Kiesewetter, Senior Research Scholar at Pollution Management Research Group, Energy, Climate, and Environment Program, IIASA

Paul Natsuo Kishimoto, Research Scholar at Integrated Assessment and Climate Change Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Zbigniew Klimont, Research Group Leader at Pollution Management Research Group, and Principal Research Scholar at Energy, Climate, and Environment Program, IIASA

Marta Kozicka, Research Scholar at Integrated Biosphere Futures Research Group, Biodiversity and Natural Resources Program, IIASA

Andrey Krasovskiy, Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program, IIASA

Florian Kraxner, Research Group Leader and Principal Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program, IIASA

Volker Krey, Research Group Leader of Integrated Assessment and Climate Change Research Group, Principal Research Scholar at Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Michael Kuhn, Program Director and Principal Research Scholar at Economic Frontiers Program, IIASA

David Leclère, Senior Research Scholar at Integrated Biosphere Futures Research Group, Biodiversity and Natural Resources Program, IIASA

Qi Liu, Guest Research Scholar at Economic Frontiers Program, IIASA; Postdoctoral Research Fellow at Sichuan University

Wolfgang Lutz, Interim Deputy Director General for Science, IIASA; Professor of Demography at University of Vienna

Landis MacKellar, Emeritus Research Scholar at Social Cohesion, Health, and Wellbeing Research Group, Population and Just Societies Program, IIASA

Alessio Mastrucci, Research Scholar at Sustainable Service Systems Research Group and Transformative Institutional and Social Solutions Research Group, Energy, Climate, and Environment Program, IIASA

Jihoon Min, Research Scholar at Transformative Institutional and Social Solutions Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Nebojsa Nakicenovic, Distinguished Emeritus Research Scholar at Energy, Climate and Environment Program and Former Deputy Director General/CEO (2008-2018), IIASA

Leila Niamir, Research Scholar at Transformative Institutional and Social Solutions Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA

Sten Nilsson, Guest Senior Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program, Former Program Leader at Forestry Program (1990-1998), and Former Acting Director (2008-2009), IIASA

Brian O'Neill, Earth Scientist and Laboratory Fellow at the Joint Global Change Research Institute, Pacific Northwest National Laboratory (PNNL); Former Program Leader at Population and Climate Change Program (2005-2009), IIASA

Shonali Pachauri, Research Group Leader at Transformative Institutional and Social Solutions Research Group, and Principal Research Scholar at Energy, Climate, and Environment Program, IIASA

Setu Pelz, Research Scholar at Transformative Institutional and Social Solutions Research Group, Energy, Climate, and Environment Program, IIASA

Pallav Purohit, Senior Research Scholar at Pollution Management Research Group, Energy, Climate, and Environment Program, IIASA

Peter Rafaj, Senior Research Scholar at Pollution Management Research Group and Integrated Assessment and Climate Change Research Group, Energy, Climate, and Environment Program, IIASA

Claudia Reiter, Researcher at the Institute for Advanced Studies Vienna; Researcher and Lecturer at University of Vienna; Guest Research Scholar at Economic Frontiers Program, IIASA

Keywan Riahi, Program Director and Principal Research Scholar at Energy, Climate, and Environment Program, IIASA

Hans-Holger Rogner, Emeritus Research Scholar at Integrated Assessment and Climate Change Research Group, Energy, Climate, and Environment Program, IIASA

Elena Rovenskaya, Program Director and Principal Research Scholar at Advancing Systems Analysis Program, IIASA

Warren C. Sanderson, Guest Research Scholar at Social Cohesion, Health, and Wellbeing Research Group, Population and Just Societies Program, IIASA; Professor Emeritus at Stony Brook University

Sergei Scherbov, Distinguished Emeritus Research Scholar at Social Cohesion, Health, and Wellbeing Research Group, Population and Just Societies Program, IIASA; Affiliated Professor at the College of Population Studies, Chulalongkorn University

Dmitry Shchepashchenko, Senior Research Scholar at Agriculture, Forestry, and Ecosystem Services Research Group, Biodiversity and Natural Resources Program and Novel Data Ecosystems for Sustainability Research Group, Advancing Systems Analysis Program, IIASA

Sergey Sizov, Science Diplomacy Officer, IIASA

Ting Tang, Research Scholar at Water Security Research Group, Biodiversity and Natural Resources Program, IIASA

Gamze Ünlü, Research Scholar at Integrated Assessment and Climate Change Research Group and Transformative Institutional and Social Solutions Research Group, Energy, Climate, and Environment Program, IIASA

Albert van Jaarsveld, Director General, IIASA

Bas van Ruijven, Research Group Leader and Senior Research Scholar at Sustainable Service Systems Research Group, Senior Research Scholar at Transformative Institutional and Social Solutions Research Group and Integrated Assessment and Climate Change Research Group, Energy, Climate, and Environment Program, IIASA

David G. Victor, Professor of Innovation and Public Policy at the School of Global Policy and Strategy, UC San Diego; Adjunct Professor in Climate, Atmospheric Science & Physical Oceanography at Scripps Institution of Oceanography; Senior Fellow at The Brookings Institution

Adriano Vinca, Research Scholar at Integrated Assessment and Climate Change Research Group and Transformative Institutional and Social Solutions Research Group, Energy, Climate, and Environment Program, IIASA

Piero Visconti, Research Group Leader at Biodiversity, Ecology and Conservation Research Group, and Senior Research Scholar at Biodiversity and Natural Resources Program, IIASA

Fabian Wagner, Dean, Capacity Development and Academic Training Unit and Principal Research Scholar at Pollution Management Research Group, Energy, Climate and Environment Program, IIASA

Charlie Wilson, Senior Research Scholar at Transformative Institutional and Social Solutions Research Group and Sustainable Service Systems Research Group, Energy, Climate, and Environment Program, IIASA; Jackson Senior Research Fellow at Oriel College; Professor of Energy and Climate Change at University of Oxford

Wilfried Winiwarter, Senior Research Scholar at Pollution Management Research Group, Energy, Climate, and Environment Program, IIASA

Behnam Zakeri, Senior Research Scholar at Integrated Assessment and Climate Change Research Group, Energy, Climate, and Environment Program, IIASA

Caroline Zimm, Research Scholar at Equity and Justice Research Group, Population and Just Societies Program and Transformative Institutional and Social Solutions Research Group, Energy, Climate, and Environment Program, IIASA

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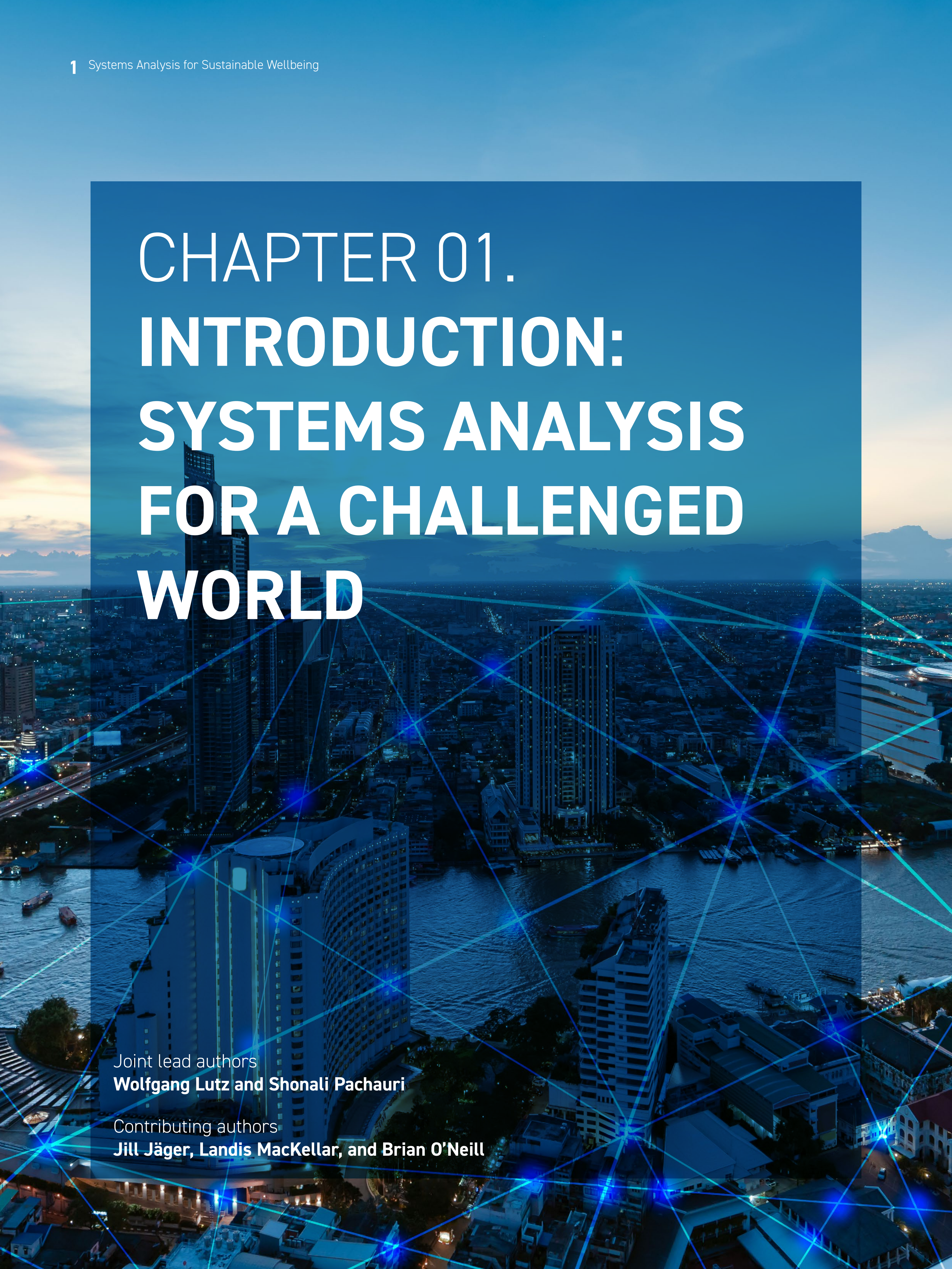


CHAPTER 01.

INTRODUCTION: SYSTEMS ANALYSIS FOR A CHALLENGED WORLD

Joint lead authors
Wolfgang Lutz and Shonali Pachauri

Contributing authors
Jill Jäger, Landis MacKellar, and Brian O'Neill

This report examines critical global trends in the world from a long-term perspective, crossing established scientific disciplines and geo-political divides. It chronicles the half-century-long history of the International Institute for Applied Systems Analysis (IIASA), which was established to address precisely such challenges at a time when the world was politically dominated by the Cold War.

Back then, science was compartmentalized into highly differentiated disciplines with incompatible research paradigms, but at the same time, there was an increasing understanding that the world faced unprecedented global environmental challenges. The IIASA Charter was signed at the Royal Society in London in October 1972, and IIASA's scientific work started at Schloss Laxenburg (south of Vienna, Austria) in September 1973.

This report focuses on the changing ways of thinking about the future and the advancement of the scientific toolbox to address future challenges as they were perceived and anticipated at different points in time since the mid-20th century. By necessity, it does not provide a comprehensive account of the vast and rich array of research and reflection, multidisciplinary analysis, modeling, and development of stakeholder processes for deciding on wicked policy issues that has been, and continues to be, the focus of IIASA's work.

In its early years, IIASA was a center of what was then called global modeling; it was the place where the first systematic studies on global climate change, which would eventually contribute to the establishment of the Intergovernmental Panel on Climate Change (IPCC) (see Box 1.1) were coordinated. It then became a leading center for the development of comprehensive long-term scenarios (e.g., *Special Report on Emissions Scenarios [SRES]* and the Shared Socioeconomic Pathways [SSPs] referenced further below) that have been widely used in the global change research community. IIASA played a pioneering role in developing integrated models of energy systems, air pollution, and climate-altering emissions, land use change, food production and biodiversity, and water systems. IIASA also became a pioneer in the multidisciplinary analysis and modeling of risk, from nuclear power to climate extremes. It became a leader in global multidimensional population analysis; its researchers were the first body to anticipate that the end of world population growth was on the horizon and to integrate human capital into population modeling. Over the years, IIASA has tried to bring these cutting-edge sectoral models and tools together in a multi-disciplinary manner, as most recently done in *The World in 2050* studies (see Figure 1.1).[1]

IIASA's mission is to help establish the scientific basis for the transition to sustainable development. With the 2030 Agenda and its 17 Sustainable Development Goals (SDGs) and 169 more specific targets, there is a global mandate on the table. This set of goals and targets has been the basis of many scientific studies about the optimal pathways needed to reach them. Recent assessments have shown that we are behind in reaching many, if not most, of them,[2] and this concern is the focus of ongoing discussions. It has also become clear that the bottom-up nature of defining the SDGs and targets has resulted in many overlaps and trade-offs that have not been made explicit,[3] while the large number of indicators, 248, has contributed to confusion and possible disorientation among the many stakeholders concerned with implementing and tracking these. The highly inclusive process of defining numerous targets has understandably resulted in an extremely broad agenda—which, in "leaving no one behind," imposes a vast range of concerns and imbalances. In this context, the current report tries to focus on the big picture and clarify sustainable wellbeing for all as the ultimate goal.

The year 2023 also marks the 40th anniversary of the commissioning of the Brundtland Report—chaired by the then Norwegian environment minister Gro Harlem Brundtland—which was published in 1987 under the title *Our Common Future*.[4] It is noteworthy that the chapters of that report closely resemble the main thematic programs of IIASA research over the past decades: (a) Population and human capital; (b) Food security, biodiversity, and natural resources; and (c) Energy, technology, and climate change. These three broad themes also provide the structure of this concise overview of IIASA contributions to thinking about, modeling, and anticipating the future in policy-relevant ways as these activities have evolved over the past half century.

These themes are the basis of Chapters 2–4 of the current report. Chapter 5 brings these broad sectors together to highlight and illustrate a truly comprehensive systems modeling approach that has human wellbeing as the critical output parameter. In its concluding Chapter 6, the report singles out three priority areas for policymaking to trigger discussions about a post-2030 Agenda.

Figure 1.1. **Six exemplary transformations identified by TWI2050**

Note. TWI2020 focuses on six transformations that capture much of the global, regional, and local dynamics and encompass major drivers of future changes. Together they give a people-centered perspective: building local, national and global societies and economies which secure wealth creation, poverty reduction, fair distribution and inclusiveness necessary for human prosperity. They are necessary and potentially sufficient to achieve the SDGs if addressed holistically in unison. Source: TWI2050.[1]

Box 1.1. IIASA's early contributions to the climate change debate

By Jill Jäger

In the 1970s the IIASA Energy and Climate Subtask, supported by the United Nations Environment Programme, studied the possible impact on global climate of the three major, medium- to long-term energy options: nuclear, fossil fuel, and solar energy systems. As part of this work, a workshop was held at IIASA in February 1978 on Carbon Dioxide, Climate and Society.[5] This workshop consolidated knowledge on the bio-geophysical aspects of the carbon cycle and on the impacts of increased carbon dioxide concentrations, and it also considered the implications of this knowledge for decision-making on energy strategies.[6,7] Foreshadowing debates that would receive increasing attention in subsequent decades, the participants asked: "Suppose, for example, we imagine a kind of 'worst case' in which we burn up most of our economically recoverable fossil fuel by the year 2100, and this results in an 8°–10°C global average warming. What will this mean in terms of food, fisheries, water resources, transportation, and so forth? Is this process reversible?"

Among the many points that are still relevant today, the workshop participants concluded that in view of the uncertainties associated with almost every aspect of the "CO2 issue," policies to increase the use of coal because of its great abundance were unjustified and the maintenance of great flexibility in energy supply policies was necessary. Furthermore, it was noted that in order "to assure the social wellbeing of the global community, basic research must also be conducted in and across several areas of the social sciences." In addition, it was pointed out that efforts to reduce energy demand were just as important as those to maintain an appropriate energy supply and that energy demand could be reduced on a global scale without causing unacceptable changes in global wellbeing.

The results of this workshop and further research in the IIASA Energy and Climate Subtask were presented in IIASA's contribution[8] to the first World Climate Conference. Following that conference, with the establishment of the World Climate Programme, the scientific community continued to research and debate the issue of anthropogenic climate change; and the next international scientific conference on the greenhouse effect and climate change took place in Villach, Austria, in October 1985.[9,10] IIASA's contribution to that conference was a presentation by William Clark,[11] leader of IIASA's initiative on Sustainable Development of the Biosphere. The presentation, entitled "On the Practical Implications of the Carbon Dioxide Question," suggested that multifaceted, complex problems like the population problem, the problem of economic development, and indeed the carbon dioxide problem can better be described as "messes." It further postulated that experience with messes suggested that any attempt to resolve them would be futile, if it presumed the existence of a few key "decisions" or "decision-makers." Thus, the conclusion was that with a mess of multiple actors and actions, no-one's needs will be served by single "bottom line" assessments that purport to speak for all people and all times. These were key messages, given that the Villach Conference called for further periodic assessments of the climate change issue and for the initiation, if deemed necessary, of the negotiation of a global convention.

1.1 The world in 1972/3

On 4 October 1972, a group of distinguished international scientists, including representatives from the United States, the Soviet Union, and ten other countries from the Eastern and Western blocs, met at the Royal Society in London to sign the charter establishing the International Institute for Applied Systems Analysis (IIASA). This was a remarkable initiative taken at the height of the Cold War, reflecting the insight that, despite prevailing ideological and strategic conflicts, truly global challenges exist and that to address them, collaboration is needed among the world's best scientists from a broad range of disciplines using the best methods of analysis available. The methods of the time were the newly available mathematical modeling techniques of systems analysis. But to ensure that IIASA would deal with the most pressing real-world problems, in addition to developing innovative mathematical methods the founding fathers of IIASA, after some deliberation, decided that the name of the institute should encompass the term "Applied Systems Analysis."

The year 1972 was also the year when the Club of Rome published its *Limits to Growth.*[12] This applied methods of systems analysis that had evolved from the engineering tradition at Massachusetts Institute of Technology (MIT) and aimed to develop a comprehensive global model linking population trends with energy, food supply, economic growth and environmental pollution, including explicit consideration of assumed inter-dependencies and feedbacks, for many decades into the future. This model was the first to illustrate in a quantitative manner—and based on the then new computer modeling techniques—that ongoing global trends were not sustainable and would result in a crash, with industrial output and food supply collapsing, and a large proportion of the world population perishing. The collapse was an inevitable outcome, as technology learning and performance were assumed constant in the model. In the baseline scenario this collapse was projected for around 2020.

Although the projected complete systemic collapse has not happened (thus far), studies have shown that some of the projections were accurate.[14] Looking back over the past half century with respect to global change and sustainable development analysis, there is no doubt that the *Limits to Growth* publication, together with the Stockholm Environment Conference in 1972, opened the door to comprehensive scientific analyses of the complex human population, and pinpointed the economic development and environment interactions that coincided with the establishment of IIASA. During the 1970s IIASA became the center for global modeling; in 1981 it published a seminal two-volume flagship report entitled *Energy in a Finite World*[15,16] and in 1982 a book entitled *Groping in the Dark: The First Decade of Global Modelling.*[17] A few years later, the *Brundtland Report* broadened the international discussions, not only among scientists but also among the international political and diplomatic community, and established an agenda for global sustainable development policy priorities for decades into the future. Actually, a 1986 IIASA Report,[18] predating the 1987 *Brundtland Report*, was the first comprehensive scientific text on sustainable development.

The Millennium Development Goals (MDGs, 2000–2015) focusing on development and poverty, were criticized as preaching to the developing world. The subsequent SDGs (2015–2030) were broader, incorporating global environmental sustainability and, significantly, highlighted the global responsibilities of high-income, not just low-income, countries, to contribute to global sustainability.

1.2 Apocalypse postponed

The *Limits to Growth* study was by no means universally saluted, but it was not the only warning of impending catastrophe published around that time. Indeed, when IIASA was founded in 1972, environmental apocalypse was the popular order of the day. In *The Population Bomb,*[19] Paul Ehrlich advocated for action to limit population growth and to avoid a global famine and civil wars, which he saw as inevitable and on the verge in the next decades. Garrett Hardin's *Tragedy of the Commons*[20] took a strong stance against the welfare state which supposedly encouraged "overbreeding," leading to the depletion of the commons. This was soon followed by his more provocative *Lifeboat Ethics,*[21] in which denying support to poor countries was proposed as a necessary global triage. The first Earth Day was held on 22 April 1970 in the USA, before turning global in 1990. The I=PAT equation, which proposes that the impacts of the human population on the environment (I) are the product of the population size (P), affluence (A), and technology (T) of this population, was first published in 1971,[22] and a furious debate raged between Ehrlich, arguing that environmental deterioration was driven by population growth, and Barry Commoner, author of *The Closing Circle,*[23] who argued that the culprits were over-consumption and polluting technologies. Subsequently, the field of industrial ecology, essentially the tracing of material flows through production processes, was applied to quantify pollution and waste (and figured in IIASA research).

Many sectoral analyses added to the sense of gloom. In the influential *State of the World Series* of the Worldwatch Institute, Lester Brown argued that the world food system was in crisis from soil loss, water scarcity, rising global meat consumption, and limitations of the nitrogen cycle. The price of "prime farmland" in the USA became the subject of close scrutiny. The 1973 energy crisis saw the price of oil quadruple and revealed the world's dependence on a single oil-producing region. In an exercise using a small dynamic model, geologist M. King Hubbert predicted that continental U.S. oil production would begin to decline in the early 1970s, a shock when it occurred to an industry which had predicted it would expand indefinitely. In the wake of the increase in the price of energy came increases in the price of food, and the global economy entered a period of stagflation—slow growth combined with high inflation. Strategic materials were a matter of concern—it was predicted that, as a quarter of Germany's GDP was related to the automobile sector and automobiles cannot be manufactured without chromium, and as South Africa was the main source of chromium, an embargo on the export of chromium from that country could see German output fall by 25%.

None of this was completely new. In the years following World War II, concerns over materials shortages in the USA were so acute that the Ford Foundation financed a landmark study, *Resources in America's Future,*[24] which eventually resulted in the foundation of Resources for the Future: this was then, and still is, a leading research institution focusing on resource and environmental issues. That study argued that, while shortages were bound to occur, so too were responses, as price increases brought forth new sources and stimulated resource-saving technical progress. As the seventies progressed into the eighties, two distinct styles of analysis emerged. On one side were traditional economic arguments, typified by Julian Simon's *The Ultimate Resource,*[25] in which human ingenuity was seen as capable of pushing limits indefinitely. Scarcity was relative, substitutability all but infinite, if the price system was allowed to operate. Alternatively, there were arguments from the upstart school of ecological economics, whose best-known proponent was Herman Daly, in which scarcity was absolute (in large part due to thermodynamic considerations), substitutability meager, and limits already being tested.

There was also a middle ground. In its 1986 study on population and development,[26] the U.S. National Academy of Sciences argued that, while the price system is good at dealing with non-renewable resources where property rights are well established, it is not nearly as good at dealing with renewable ones, where common property and public good problems are rife—the "tragedy of the commons," with the Earth's atmosphere being the classic case.

It is fair to say from the perspective of 2023 that, on balance, the worst of these fears have not materialized, at least not up to now. New sources of food and fiber, energy, and materials have been developed. Invention, innovation, and technology, above all the information revolution, have shattered once-binding limits. But the old fears refuse to go away, and new ones have arisen:

- Climate change continues unabated, with effective and timely collective action apparently impossible to achieve. Despite the development of renewable energy, the world remains fossil-fuel dependent. There is no sign that the world's largest coal consumers are going to forego exploitation of that resource, which they hold in abundance. No masterpiece of science diplomacy has been able to dispel the suspicion that Northern environmentalism seeks to choke justifiable Southern claims to develop and grow.
- As scientific understanding has grown, it has become apparent that the negative effects of climate change, at least in the form of extreme weather events and natural disasters, are materializing much faster than expected. Tipping points are now a source of broad concern.
- Poverty and extreme deprivation have still not been abolished, and the gap between the rich and the poor is widening nearly everywhere.
- In food as well as industrial goods, the COVID-19 pandemic and the Russia–Ukraine War have again revealed that there are choke-points in the global supply system.
- Between pollution and over-exploitation, marine and other fragile ecosystems are under threat.
- There is no sign that countries are willing to forego exploitation of tropical forest areas for agriculture and timber production. Biodiversity loss proceeds apace.
- A new problem that was not a source of major public concern until the last decade or so has emerged—resurgent communicable disease. Failure to react effectively to the H1N1 influenza scare and SARS earlier this century shows every sign of being repeated in the wake of the global COVID-19 pandemic.

Finally, two meta-problems cut across all these concerns. The first, brought to the fore by the COVID-19 crisis, is the generalized loss of faith in science (and of trust in establishment knowledge brokers such as the mainstream press). This skepticism, born of crisis-fatigue and political polarization, and weaponized by social media and the internet, is one of the things to be really worried about. The Artificial Intelligence revolution, still in its infancy, raises the specter of a world in which critical thinking and the expression of cogent opinions in written form are less necessary than they once were. We risk a world in which human knowledge is a jumble of ephemera to be dipped into and reorganized by computer and thus in conflict with the scientific paradigm. The second meta-problem is the obvious failure of global governance to produce a shared vision of problems and feasible solutions. The Brundtland Commission's vision of a common future, now embedded in the SDGs and the 2015 Paris Agreement, is long on aspirations but short on results.

If this analysis is correct, the apocalypse that was predicted in the early seventies and continued to hold sway well into the eighties and nineties was avoided—largely for the reasons that the skeptics advanced at the time—but it may very well have been merely postponed. The question today then is can we envisage a scenario where technical optimism and human ingenuity can avert the advancing storms?

1.3 Climate change, the dominant concern

From the early days of IIASA, climate change has figured prominently on the institute's scientific agenda. Understanding and assessing the effects of resources and energy production and use on the environment and climate have been, and remain, an important core area of research, particularly within the sphere of energy systems research at IIASA. In addition to understanding the contributions of human activities to climate change, assessment of the impacts of climate change on humans and the risks of climate change for ecosystems and natural resources have also been an important part of the IIASA research agenda.

During the 1970s the important question was raised as to how the large amounts of waste heat associated with generating secondary energy forms (e.g., electricity) from primary energy (e.g., coal) and the interconnected problem of carbon dioxide (CO2) releases into the atmosphere affected the climate system. Nordhaus's 1975 paper[27] alluded to the importance of greenhouse gas emissions from the energy system for global temperature and sea-level rise, and it analyzed ways of reducing emissions of carbon dioxide, either by reducing energy consumption or substituting non-carbon-based fuels for carbon-based fuels through carbon pricing. The 1978 IIASA Workshop on Carbon Dioxide, Climate and Society, one of the earliest international assessments of the climate problem, concluded that because knowledge of the climate system and the carbon cycle was so uncertain, a prudent energy policy would be to maintain flexibility.

With the publication of *Energy in a Finite World: A Global Systems Analysis,*[16] a broader cross-program focus on the interactions between climate and society was identified as important for understanding the impact of possible climate change on human activities and the potential of human activities to affect the climate. Following this, the International Energy Workshop (IEW), a joint venture created by IIASA with Stanford University, was established in 1981. It aimed to compare published energy projections (and later, associated emissions) and reconcile differences in these with authors from across a broad network of institutions. It was also around this time that new approaches to climate impact assessment, including a greater focus on integrated risk assessment, scenario analysis, and global modeling, came under the spotlight at IIASA. As well as understanding the drivers of climate-altering emissions, the importance of understanding the impacts of climate variability and change on food systems was also emphasized. Between 1983 and 1986, supported by the United Nations Environment Programme, the Climate Impacts Project at IIASA assessed the vulnerability of food production in climate-sensitive areas.

The establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988 ushered in a new era of IIASA contributions to the understanding and shaping of climate change science and policy. Bert Bolin, the first chair of the IPCC, was chairperson of IIASA's Science Advisory Committee in the seventies and eighties. Thus, from the moment of the IPCC's inception, IIASA has strongly supported the scientific foundation of the IPCC assessments, particularly through scenario modeling and analysis, which have become an important backbone and integrating element of the reports. IIASA organized the first international workshop on the comparative assessment of climate change mitigation and its potential impacts and adaptation strategies in 1992. One of the key findings of the workshop was the need for integrated assessment, something that was ideally suited to IIASA's interdisciplinary and systems analytical approach.

The *Special Report on Emissions Scenarios (SRES),*[28] on which work began in 1996, provided the first set of scenarios that described consistent demographic, social, economic, technological, and environmental developments driving emissions of greenhouse gases due to human activities; it combined qualitative and quantitative approaches to developing emissions scenarios. The development of these scenarios was coordinated by Nebojsa Nakicenovic at IIASA. The report produced the first set of comprehensive scenarios of greenhouse gas emissions for the 21st century, which came to underpin the IPCC's Third and Fourth

Assessment Reports. The Third Assessment Report, the first to be based on IIASA scenarios, also led to the development of the Assessments of Impacts and Adaptations to Climate Change Program, which sought to advance scientific understanding of climate change vulnerabilities and adaptation options in developing countries through capacity building.

In the 2000s, IIASA's Greenhouse Gas Initiative (GGI), an interdisciplinary research effort that linked all major IIASA research programs, including population, energy, technology, forestry, as well as land use changes and agriculture, conducted research on policy-relevant aspects of addressing climate change, both basic and applied and from a near- and long-term perspective. The work under the GGI developed a new set of scenarios derived from the SRES scenarios.[29] In this work, the original SRES scenarios were revised and updated to reflect new information and also to incorporate the results of scenario analyses performed with the help of a coupled integrated modeling and assessment framework based on detailed IIASA models of energy and industrial systems, agriculture, and forests. This new framework aimed to improve scenario consistency, and much of the work that went into it then fed into the IPCC's Fifth Assessment Report. During this period, IIASA also expanded its work on modeling climate risks and identifying efficient risk-reduction activities to support safety nets for the most vulnerable.[30]

In 2009 the climate community published the Representative Concentration Pathways (RCPs)—four pathways for emissions, concentrations, and radiative forcing. Following this in 2011, work spearheaded by IIASA began on developing and quantifying the Shared Socioeconomic Pathways (SSPs)—five possible socioeconomic and demographic futures that human societies might follow over the next century. The SSPs provided a new framework of scenarios for the climate research community that facilitated an integrated analysis of future climate impacts, vulnerabilities, adaptation, and mitigation.[31–33] Each SSP includes a specific narrative that serves to identify an internally consistent set of assumptions for the quantification of socioeconomic and demographic change, such as population growth, economic development, and technological progress. The SSP–RCP framework of scenarios has been the basis of the IPCC's Sixth Assessment Report.

As steering committee member and co-chair of the International Committee on New Integrated Climate Change Assessment Scenarios (ICONICS), IIASA had a large presence at the first Scenarios Forum in 2019. Following this, an in-depth analysis of literature applying the SSP–RCP scenarios was undertaken and the next steps for the scenario process were identified. Encouragingly, the findings indicated that the scenarios framework has enabled research that had not previously been possible and that integrated scenarios are increasingly being applied to different sectors and regions.[34] IIASA then hosted the second Scenarios Forum in 2022. The meeting informed scenario use in preparation for the next seventh cycle of IPCC Assessment Reports and is helping foster integrated climate change and sustainability research.[35]

Today, IIASA's engagement in climate change science and policy continues to frame much of its research agenda. The focus now is on better understanding interdependencies between climate impacts, adaptation and mitigation measures, and the temporal evolution and capacity of the broader socioeconomic system to cope with the climate challenge. In addition, some of the new elements of emphasis with respect to climate change science and policy at IIASA include embedding national planning perspectives and development needs, a primary focus on human wellbeing, an obligation to safeguard the global commons, and the achievement of justice within and between generations and across regions (Box 1.2).

Box 1.2. Wellbeing, demography, and climate change

By Brian O'Neill

Over the past 50 years, population has been treated as a driver of environmental change and, more recently, as a determinant of exposure and vulnerability to environmental change. Both of those roles are important, and there is a lot of good work on both topics.

Looking forward, we need to increasingly see population as the locus of outcomes that we are actually interested in: the wellbeing of the human population.

Objective wellbeing reflects the functioning and capabilities of individuals.[36] Capabilities refer to opportunities that you have available to you and the freedom to choose among them to create a life that you value. Objective wellbeing is typically measured along a number of dimensions, including health, education, security, living standards, environmental conditions, and social factors. We can expand the security dimension of wellbeing to include dimensions of security that are especially important to the climate change issue: food, water, and energy security. This can be also complemented by subjective measures such as happiness and life satisfaction.

Wellbeing is amenable to analysis and should be the organizing principle of our climate change studies. Currently it plays a secondary role. The bulk of the climate literature is occupied by outcomes like heat waves, flooding, crop yields, and sometimes crop prices. But these outcomes are not direct measures of wellbeing. Mortality and morbidity from heat waves or flooding are; losses to standards of living from damage caused by extreme events are; hunger is. We should not confuse one with the other. More heat waves do not necessarily mean more heat wave deaths, for example, because population exposure and vulnerability will be changing at the same time.

One way we can improve the focus on wellbeing is to change how we approach and communicate climate change research, including population–climate change research. Current practice distorts our picture of what the future actually holds in terms of wellbeing. That practice is one that focuses on the additional effect of climate change on wellbeing, rather than the total, absolute level of wellbeing driven by all causes.

As an example, consider hunger as a metric of food security (one of the dimensions of wellbeing). What we hear is that climate change will drive tens of millions of people into hunger. That is true, in that it is consistent with the literature. At the same time, it is also true that there are around 700 million people at risk of hunger today, and that hunger is projected to decline by about two-thirds to around 250 million by 2050, even accounting for climate change.[37]

How can both be true? The decline from 700 to 250 million is the total, absolute number of people in hunger; the "total risk of hunger." The tens of millions are the additional people hungry due to climate change in 2050. That is, without climate change in 2050, there would have been around 220 million hungry, rather than 250 million. What is typically focused on is the tens of millions hungry; what gets lost is the massive improvement in under-nutrition over time, even though it is slowed by climate change.

We should be focusing on the total absolute risk to human wellbeing. Climate change effects are absolutely worth considering, but we need to account for all factors driving wellbeing and consider climate effects within that context. This applies to our population–climate research as well.

Over the next 50 years, it is hoped that IIASA will continue to expand its work on a demography of wellbeing, and that the rest of the population and climate change world can join in that challenge.

1.4 Quantifying sustainable human wellbeing for all as the "ultimate goal" of sustainable development

The idea that human wellbeing is the ultimate goal of sustainable development is not a new one. This has been explored by sustainability science—in inter- and transdisciplinary approaches to studying the scientific foundations of sustainable development.[38,39] Under this approach, wellbeing is seen as resulting from a combination of different forms of capital (conventionally defined as natural, human, and economic), conditioned by institutions and knowledge. These determinants of wellbeing work together synergistically, resulting in either increasing or decreasing wellbeing trends among different population groups. There is an extensive body of literature regarding how changes in those forms of capital interact and jointly determine wellbeing.

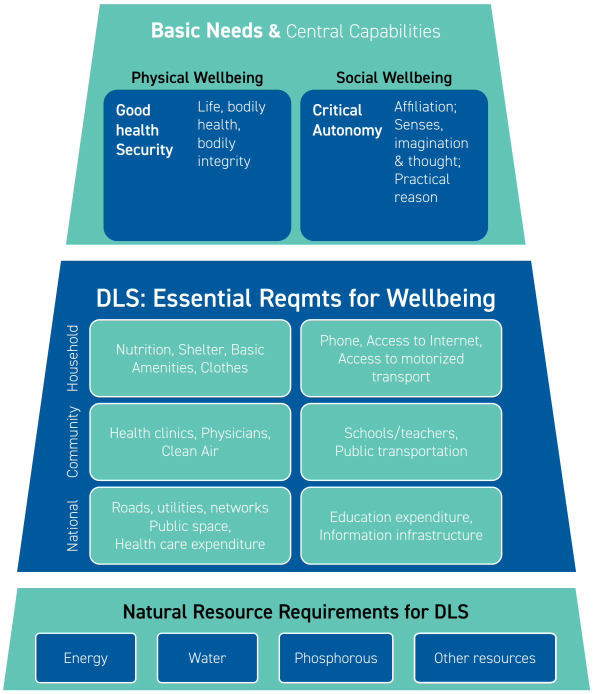
One highly controversial issue when operationalizing and assessing the level of human wellbeing is whether to focus on objective or subjective indicators. This controversy goes back to ancient Greece to Aristotle's concept of the state of eudaimonia, commonly translated as "happiness" or "welfare." Aristotle believed that external fortunes or goods are required for virtue and thus happiness (objective indicators), while another ethics school, the Stoics, believed that achievement of eudaimonia was possible only through the development of our internal state and our character (subjective indicators).

The proponents of using subjective measures such as level of happiness or life satisfaction see wellbeing as a deeply personal matter that only the individual can assess and state, often measured on a scale of 0 to 10.[40] On the other hand, the proponents of objective indicators—the Human Development Index (HDI) of the United Nations Development Programme (UNDP) being one—point to the fact that expressions of happiness tend to be transitory and can be volatile without any change occurring in the person's actual living conditions. According to researchers preferring to focus on objective living conditions, wellbeing is the enablement of humans to achieve their highest level of functioning in a given context.[41–43] Other recent efforts to define quantitative indicators of wellbeing include the Better Life Index of the Organization for Economic Co-operation and Development (OECD),[44] or the Happy Planet Index.[45] Such indicators have in common that they try to go beyond the conventional income and production accounts and to follow the insights gained from the *Mismeasuring Our Lives* report.[46]

Another topic of relevance for considering the effects of environmental and other changes on human wellbeing is the heterogeneity of human populations. In environmental studies, it is typically assumed that spatial heterogeneity is of central importance and that where people live is a key determinant of their living conditions and vulnerability to, for example, climate change. Increasing spatial detail in the population models has helped to address this issue. But social heterogeneity is equally important. Not all people living in a given location act and react in the same way, and not all are equally vulnerable to environmental and other challenges. Focusing only on averages and representative agents—as many environmental and economic models do—does not capture this ingrained heterogeneity that has been shown to be highly relevant for outcomes.[47,48] Vulnerability to natural disasters, for example, differs significantly among different segments of the population: women may be affected differently from men, children differently from adults, and the less educated differently from the more educated. This is independent of the place of residence, which is sometimes the only variable considered in vulnerability studies. And as differential vulnerability is essential for capturing the effects of social, economic, and environmental changes on wellbeing for all, this aspect also requires special attention.

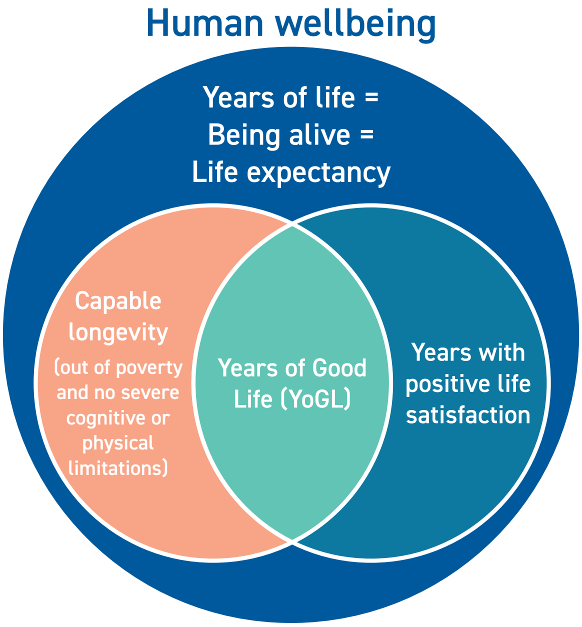
In the last decade, several efforts at IIASA have focused on addressing the challenge of defining and operationalizing empirical measures of human wellbeing, keeping in mind the need for these to capture spatial and social heterogeneity and to be suitable for use as a sustainability criterion. One of these, the Decent Living Standards (DLS) proposal, aims to provide a comprehensive measure of the material prerequisites that enable human wellbeing (see Figure 1.2).[49,50] Another indicator that has been designed to meet all these criteria is Years of Good Life (YoGL, see Figure 1.3). The YoGL considers a year of life as a good year if people are above a minimum threshold in both subjective life satisfaction and objective indicators such as being out of poverty and above certain thresholds of physical and mental health.[51] This can be assessed for national populations as well as subgroups of the population and can be compared over long time periods.

Figure 1.2. **Decent Living Standards (DLS): Hierarchy of material requirements and their derivation**



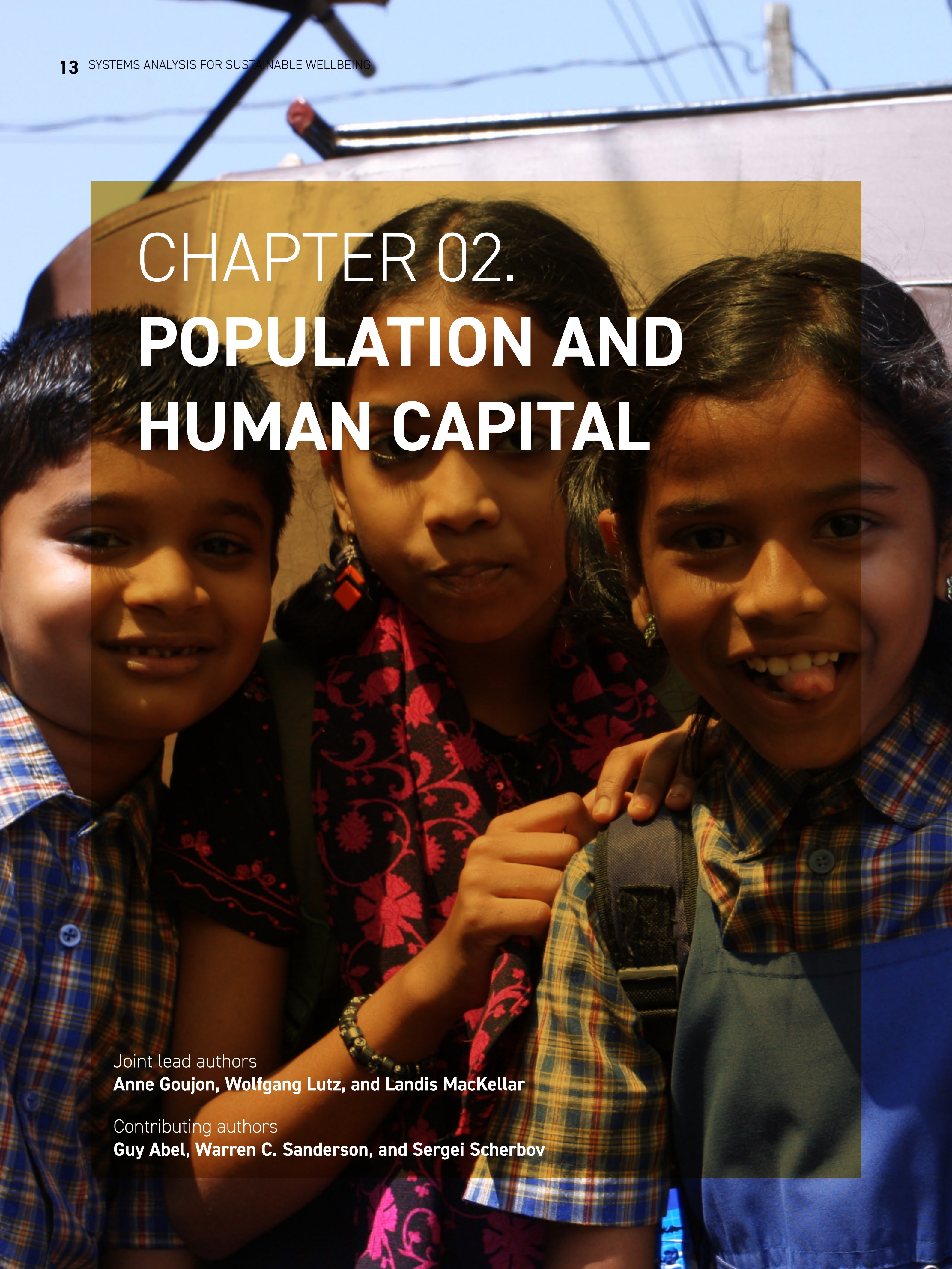
Note. Source: Rao and Min (2018).[50] Adapted under the terms of the Creative Commons Attribution 4.0 International License.

Figure 1.3. **Dimensions of Years of Good Life (YoGL), a wellbeing indicator**



Note. Source: Lutz et al. (2021).[51] Reprinted under Creative Commons Attribution License 4.0 (CC BY).

In Chapter 5 of the report, which focuses on integrated systems modeling, we present one illustration of how to implement the YoGL indicator as a wellbeing measure and ultimate objective of sustainable development in a system dynamics model. We study how YoGL, as measured for the world population, emerges endogenously over time under different development scenarios. We also include a comparison of this indicator with the widely used UNDP HDI. We see this effort as a starting point for better integrating our understanding of human wellbeing into how it interacts with social, economic, and environmental changes, which must continue to be on the agenda till 2030 and far beyond.



CHAPTER 02.

POPULATION AND HUMAN CAPITAL

Joint lead authors
Anne Goujon, Wolfgang Lutz, and Landis MacKellar

Contributing authors
Guy Abel, Warren C. Sanderson, and Sergei Scherbov

During the early days of IIASA in the 1970s, the population discourse was dominated by doomsday predictions about the fate of humanity (see Section 1.2). To date, these have been proven wrong, mainly because they took humans to be disempowered—incapable of adapting to circumstances[1] and lacking what Julian Simon[2] called the human ability to respond to change. The methodological developments and research implemented in the decades following the founding of IIASA have shown that, along with socioeconomic and technological developments, it is the empowerment of people that has been able to curb population growth and to influence how it will play out in the future.

Box 2.1. A brief history of population research at IIASA

From its earliest years, IIASA has been home to population-related research that aims to be on the cutting edge of methodological developments and interdisciplinary applications.

With populations having traditionally been subdivided by age and sex, IIASA from 1975–1984 introduced further characteristics into the analysis, developing the Human Settlements and Services (HSS) area as a global center for the development of multi-state demography. The substantive focus of multi-state demography was its applications to urbanization and internal migration, and the project produced reports with regional-level forecasts for all 17 IIASA member countries at that time. Under the leadership of Andrei Rogers, the international team included Frans Willekens, Luis Castro, and Donaldo Colosio, who after moving on into Mexican politics was assassinated in 1994 while a front-runner for the Mexican presidency. The Rogers–Castro migration model schedules are still in use today.

In 1984–1994, the Population Program was created under the leadership of Nathan Keyfitz, who wrote major textbooks on mathematical demography. Keyfitz moved to IIASA after retiring from Harvard University, and spearheaded early activities in probabilistic population projections and population–environment analysis. These benefited, in return, from the strong environmental research programs established at IIASA. Under Keyfitz, the Russian–American team of Anatoly Yashin and James Vaupel (later the founding director of the Max Planck Institute for Demographic Research in Rostock) made pathbreaking contributions on the dynamics of heterogeneous populations and mortality analysis, with a specific focus on the limits to human longevity.

In 1994–2019, there was another program name change. In the World Population Program, leader Wolfgang Lutz, together with Sergei Scherbov and Warren Sanderson, pioneered the application of probabilistic population projections to world population trends and were the first to point to the high probability of world population growth coming to an end within this century. With Anne Goujon and Samir KC, the team operationalized the application of multidimensional methods toward reconstructing and forecasting educational attainment distributions in all countries in the world—projections that now form the human core of the Shared Socioeconomic Pathways (SSPs) in the field of climate change analysis (see Box 2.2). Another line of research focuses on the link between population and the environment; this has led to the development of several models that have been applied to case studies on different countries in the Global South.[3,4] These include the Population, Environment, Development and Agriculture (PEDA) model,[5] the Wonderland model,[6] and Population–Development–Environment (PDE) model, as discussed in more detail in Chapter 5. In 2000 Brian O'Neill, Landis MacKellar, and Wolfgang Lutz published the first book on *Population and Climate Change*. IIASA also led the field of redefining age and aging that took into account changes in remaining life expectancy. Warren Sanderson and Sergei Scherbov summarized this work in their 2019 book *Prospective Longevity* (see Box 2.3).

In 2020 the entire research architecture of IIASA was restructured. The new Population and Just Societies Program (under the leadership first of Raya Muttarak and then of Anne Goujon) enlarged its focus by including parts of the previous IIASA Risk and Resilience (RISK) Program. It now has four research groups. The Equity and Justice (EQU) group, led by Thomas Schinko, focuses on the human dimension of selected globally relevant policy challenges with special attention to the design and application of equity and justice frameworks. The Migration and Sustainable Development (MIG) group, led by Roman Hoffmann, focuses on applying advanced data collection and estimation methods to quantify and better understand the trends, patterns, drivers, and consequences of different types of migration. Samir KC leads the Multidimensional Demographic Modeling (MDM) group which aims to advance demographic modeling methods to assess and forecast population dynamics focusing on demographic and spatial heterogeneity under different socioeconomic scenarios. The research activities of the Social Cohesion, Health, and Wellbeing (SHAW) group directly and comprehensively address the measurement of human wellbeing in its multiple dimensions, with a special focus on health as a key component and social cohesion as a key determinant of wellbeing.

2.1 What is IIASA’s contribution to advancing the field of population study?

Over the past five decades IIASA has contributed to the study of population in two broad areas; first, by developing the methods of multidimensional demography that explicitly take into consideration population heterogeneity, and second, by applying these to the modeling and forecasting of populations by age, sex, and level of educational attainment. IIASA has also advanced the methods of comprehensive studies of interactions in the Population–Development–Environment (PDE) realm and applied these in modeling exercises and case studies, as well as in analyses at the global level. Innovations by IIASA in both these fields have led to the use of multidimensional population scenarios as the “human core” of the five Shared Socioeconomic Pathways (SSPs), now widely used in climate change research and policy communities: these scenarios capture population and human capital trends with respect to climate change mitigation and to anticipating future adaptive capacity to already unavoidable climate change (see Box 2.2 and Box 2.4).

IIASA, since its very inception, has pioneered research to embed population in a broader systems-analytic framework. This requires research to articulate how, in the words of the old African–American Spiritual: “Toe bone connected to the foot bone. Foot bone connected to the heel bone. Heel bone connected to the ankle bone.” In 1972, this—more than any other requirement—demanded a mathematical orientation. In 1975 geographer Andrei Rogers joined IIASA to lead a group modeling Human Settlements and Services (HSS), including the then hot topic of operations research into the optimal location of emergency medical services. But Rogers was, at heart, a migration man, and under him, IIASA became known for multi-state population analysis and projections with an emphasis on migration—always a challenge in cohort-component projection.

The scientific contributions of Nathan Keyfitz who joined IIASA in 1984 are too broad to summarize easily, but he essentially laid the foundations for three areas in which IIASA continues to excel: probabilistic population projections, population–resource–environment interactions, and population aging.

IIASA was the first to apply probabilistic population projections to global population forecasts; these were published in a series of three papers in Nature by Lutz, Sanderson and Scherbov.[7–9] The titles of these three papers also show the evolution of thinking in the field. In 1997 everybody talked about a further doubling of world population as a given, but the paper *Doubling of World Population Unlikely* challenged this view. The 2001 paper, *The End of World Population Growth*, indicated with a probability of around 80% that world population would peak and start to decline before 2100. The 2008 paper, *The Coming Acceleration of Global Population Ageing*, shifted the focus of attention from growth to aging. IIASA spearheaded work on all three topics. Moreover, the view that we will likely see an end to world population growth before the end of the 21st century is one that is now widely shared.

Some achievements have been institutional, for example, the emergence of the Wittgenstein Centre for Demography and Global Human Capital as a global center of excellence in population research (https://www.wittgensteincentre.org). The Wittgenstein Centre is a collaboration of IIASA, the Vienna Institute of Demography of the Austrian Academy of Sciences, and the Department of Demography at the University of Vienna (initially the Vienna University of Economics and Business) based on the 2010 Wittgenstein Prize, the highest Austrian science prize.

The Young Scientists Summer Program (YSSP) at IIASA is another institutional success story. Through it, scores of young researchers have been trained in population and allied disciplines, and this has resulted in the publication of hundreds of scientific articles and large numbers of international seminars and conferences.

But the decisive contribution of IIASA has been to take mathematical demography and apply it to real-world problems in accordance with the institute's founding ethos and the needs of the demographic discipline in interaction with its users, a contribution that endures today.

Along the way, there have been numerous contributions to the study of the classic demographic dynamic parameters—fertility, mortality, migration, nuptiality, urbanization—contributions that have, in effect, changed the shape of modern demography.[10] Another important contribution has been to fully integrate education as both a driver (at microlevel) and consequence (at meso- and macrolevels) of demographic change (see Box 2.2 and Box 2.5). Better-educated young cohorts bring with them important capabilities. Moreover, education levels are a major source of demographic heterogeneity—the fertility, mortality, and migration behaviors of individuals vary strongly along the education dimension. While demographic differentials in education have long been studied (thanks, e.g., to World Fertility Surveys and Demographic and Health Surveys), IIASA first introduced them in population projections using an adaptation of the multidimensional method developed in the 1970s and 1980s at IIASA.[11]

In the space of a few decades, population projections by level of education have expanded from a case study of Mauritius[12] to every country in the world[13–15] via a series of case studies[16] and regional models.[17] The latest global update will be published in 2023.[18] The scenarios are based on both modeling and expert assessment about the future of fertility, mortality, migration, and education.[19]

Several main conclusions come out of this work. A central theme in IIASA research has been the concept of demographic metabolism. In biology, metabolism is the process by which an organism renews itself—or does not, at which point it dies. Demographic, population-wide metabolism is the permanent process by which younger generations replace older ones: new cohorts with different socioenvironmental characteristics result in their being better- or worse-educated than the last ones, better- or worse-off in the labor market, more or less progressive in attitudes and values, thereby gradually outweighing and ultimately replacing their predecessors. The process of slow but predictable cohort replacements can serve as the basis for projections for decades into the future. Projection results that take demographic metabolism into account can thus help to assess the prospects for sustainable development (see Box 2.5).

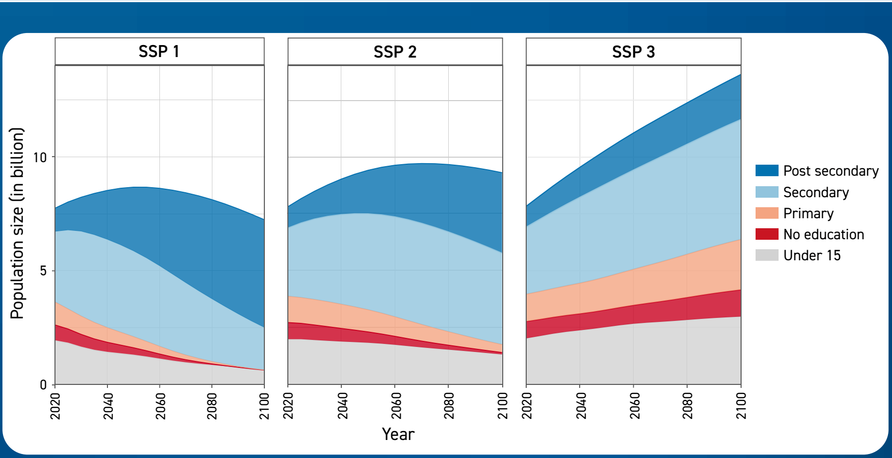
Education momentum is thus as important for demographic change as age-structure momentum. Researchers associated with IIASA have made a credible argument that the "demographic dividend," which still drives much of research on the relationship between fertility decline and economic growth is, in fact, primarily an education dividend. IIASA has been especially insistent on the role of female education as a precondition for sustainable development. The projections of educational attainment have been applied by the climate modeling communities around the Intergovernmental Panel on Climate Change (IPCC). The IPCC has utilized the different scenarios following the narratives of the Shared Socioeconomic Pathways (SSPs) to assess the relationships between socioeconomic development and climate change,[20] by investigating the role of education in reducing vulnerabilities and increasing resilience.[21] The SSP scenarios have also been employed to model the potential economic effect of future education paths in low-income countries[22] and to model in general the link between education and economic growth.[23] More recently, IIASA researchers have looked at the impact of education, particularly of women, in mitigating the labor market consequences of population aging in the countries of the European Union.[24] Further research has also been conducted on the quality of education, which is highly variable both between and within countries:[25] according to this research, school closures that were long and drastic during the COVID-19 pandemic could have adverse consequences for the human capital of countries.[26,27]

Another strand of research has looked at Population–Development–Environment (PDE) interactions in the context of sustainable development. IIASA authors produced the first book-length analysis of the links between population and climate change,[28] emphasizing in particular the weaknesses of the I=PAT model, the complex market-mediated links between population pressure and the environment, and the significant novelty of considering emissions on a per-household rather than a per-person basis. Several studies have looked at PDE interactions, and more recently, interactions directly related to climate change. To address these interrelated challenges, IIASA researchers are striving to adopt a comprehensive and integrated approach that considers the social, economic, and environmental dimensions of sustainable development. A focus of this study has been factors that will help reduce the vulnerability of human societies to the impacts of climate change. Indeed, as indicated by a series of scientific studies produced by IIASA in the past decade, research at the institute has been at the forefront in demonstrating the empirical linkages between education and vulnerability and adaptive capacity.[29–34]

Lastly, IIASA made a valuable contribution in terms of specifying a wellbeing indicator, designed to serve as the criterion variable for sustainable development. This comprehensive multidimensional indicator, Years of Good Life (YoGL), is based on a demographic approach using life table methods that consider years of life as good years only where people are above critical thresholds in subjective life satisfaction and in three objective indicators. This indicator is explained in more detail in Chapter 1, and also applied as an outcome variable in the model in Chapter 5.

Box 2.2. Human capital scenarios for all countries until 2100

Figure 2.1. **World population trends by level of education according to the three scenarios SSP1 (rapid development), SSP2 (middle of the road) and SSP3 (stalled development), 2020–2100**



Note. Source: Wittgenstein Centre Data Explorer (2018).[36]

The scenarios for the global projections published in Lutz, Butz, and KC[13] and Lutz et al.[14] and the upcoming update are constructed upon four major building blocks.

- An expert survey taken by 550 experts who provided input about fertility, mortality, and migration in 2030 and 2050 for many countries as well as rating a series of arguments underlining the major trends.
- Several meta-expert meetings on the topics of fertility, mortality, migration, and education to derive narratives for the future and develop assumptions for some of the major countries.
- A demographic projection model looking at the experience of all countries in the past to learn about the future trends of fertility, mortality, migration, and education.
- The Shared Socioeconomic Pathways (SSPs) that provide the main storyline for building the scenarios around the middle of the road scenario ("the most likely")—SSP2.

The multidimensional approach of modeling population dynamics by level of educational attainment in addition to age and sex forms the "human core" of the Shared Socioeconomic Pathways (SSPs), a set of global scenarios developed by the international climate change research community und widely used in the context of the Intergovernmental Panel on Climate Change (IPCC). These SSPs comprehensively address the socioeconomic determinants of climate change mitigation and adaptation. They are based on five different storylines about future developments in all countries of the world in terms of different demographic, social, economic, and technological dimensions.[35] In addition to the middle of the road scenario SSP2, which can also be interpreted as the most likely trend based on current assumptions, we discuss here two extremes, namely the "stalled development scenario" SSP3 and the "rapid development scenario" SSP1. Regarding education assumptions, SSP1 is highly optimistic in terms of assuming that all countries would follow the unusual experience of Singapore and South Korea in expanding their education systems, whereas SSP3 assumes the very pessimistic case of no further improvements in school enrollment[20] Figure 2.1 shows the global level results in terms of total population size for these three scenarios, spanning the wide range of possible future developments assumed under the SSP approach.

Box 2.3. Prospective longevity: A new vision of population aging

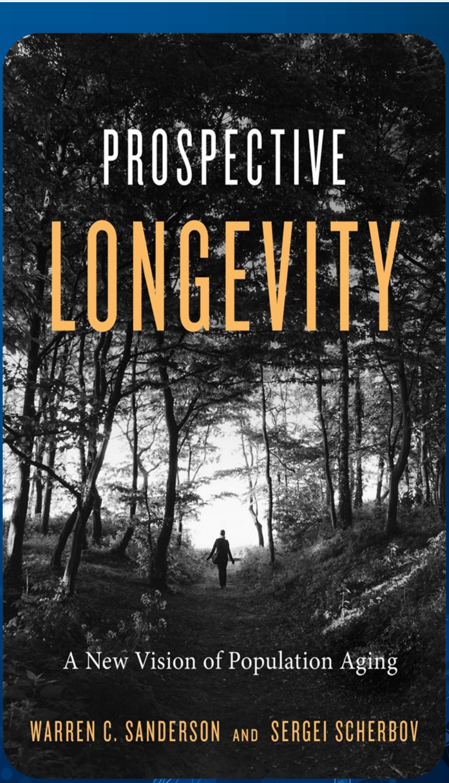
By Warren C. Sanderson and Sergei Scherbov

Aging is a complex phenomenon. We usually think of chronological age (time since birth) as a benchmark, but it is actually a backwards way of thinking about our life course. It tells us how long we've lived so far, but what about the rest of our lives? Today's 65-year-olds have different characteristics from those who were born earlier, and tomorrow's 65-year-olds are likely to be different from today's in ways that are pertinent to the study of population aging.

IIASA researchers Warren Sanderson and Sergei Scherbov have provided a new way of measuring individual and population aging, namely as well as counting how many years we have lived, we should also consider other characteristics, such as the number of years we expect to live. This combination of years will define our "prospective age." Two people in different settings who share the same chronological age probably have different prospective ages, as one will outlive the other.

Sanderson and Scherbov show how to generate demographic estimates of prospective age that can, in turn, inform better policy responses. Characteristic-based measures of age and aging help us make sense of observed patterns of survival, reorient our understanding of health in old age, and clarify the burden of old-age dependency. These metrics also produce valuable data for debates about intergenerationally equitable pensions and necessary pension reforms. Sanderson and Scherbov's pioneering results were adopted by the UN Population Division,[37] and were compiled in a book published by Harvard University Press.[38] Most recently, the World Aging Data Explorer (WADE, https://demog.iiasa.ac.at/apps/world.html) was introduced as a powerful tool for presenting and evaluating indicators of population aging.

Figure 2.2. **Book cover *Prospective Longevity*[38]**



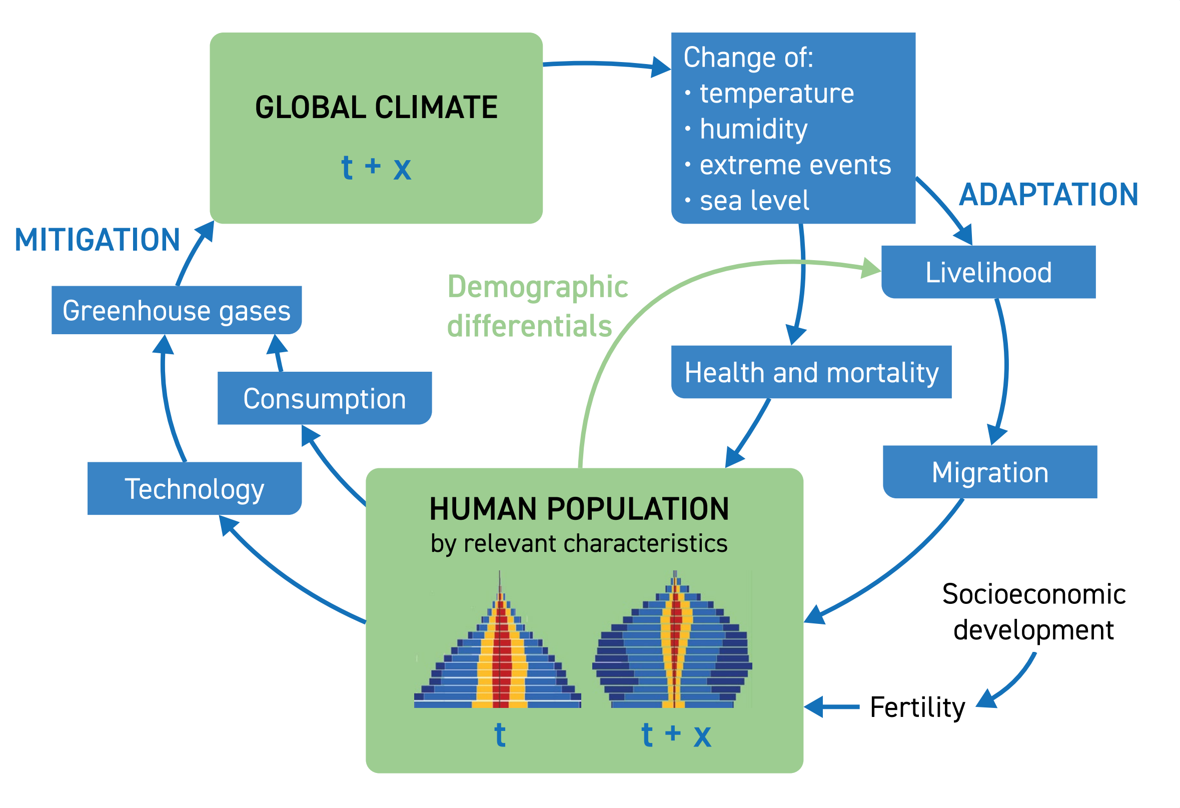
Note. Copyright 2019 by Harvard University Press.

Box 2.4. Circular link between human population and global climate systems

The link between human population and global climate systems, though complex and multifaceted, can be summarized as a circular relationship in which population growth influences climate change, and climate change, in turn, affects human populations.

Figure 2.3 provides an overview of the interconnections between human population and global climate systems; it highlights how population heterogeneity influences the impacts of population on climate change and how the feedback loop of climate change impacts demographic processes and populations with differential vulnerability and adaptive capacity.[39]

Figure 2.3. **Circular link between human population and global climate systems**

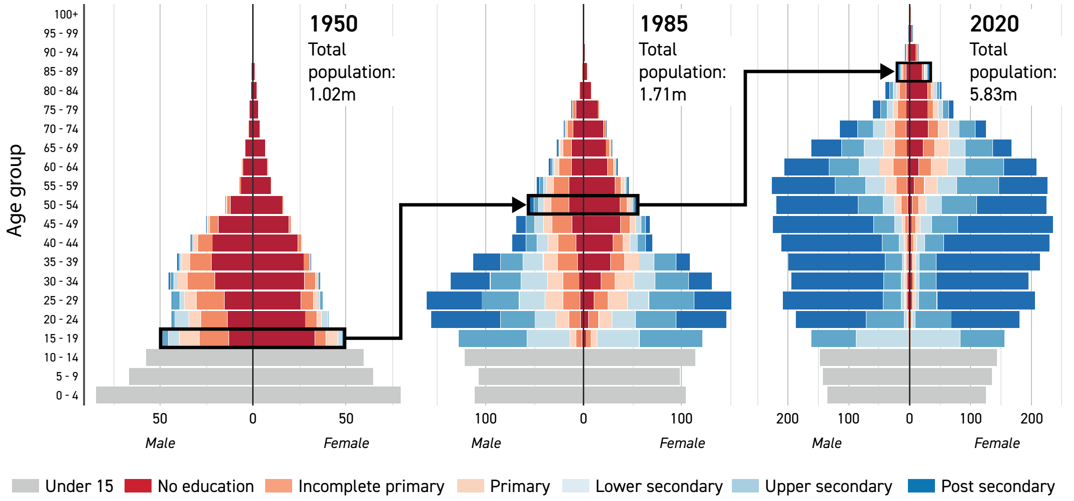


Note. Source: Lutz and Muttarak (2017).[39]

Box 2.5. Demographic metabolism in action: Reconstructing and projecting populations by age, sex, and level of educational attainment

Figure 2.4 illustrates the basic logic of the multidimensional cohort-component model which has been used to reconstruct and project the population by levels of educational attainment. It shows the education-specific age pyramids for Singapore, a country with one of the fastest education expansions in human history. Over the past 70 years, Singapore's population has gradually transformed step by step from being a low-educated least developed country to one of the most educated and richest countries in the world.

Figure 2.4. **Population pyramids by educational attainment, Singapore, 1950, 1985, 2020**



Note. Population in millions. Source: Wittgenstein Centre Data Explorer (2018).[36]

This multidimensional demographic model has been used to reconstruct educational attainment distributions not only for decades into the past, but also to project for decades into the future. Researchers from the Wittgenstein Centre for Demography and Global Human Capital (IIASA, OeAW, University of Vienna) have produced several rounds of reconstructions and projections, gradually expanding the time horizon, the number of countries, and the number of educational attainment categories.[13–15,40] The reconstructed data set now covers the period 1950–2015 for 185 countries and six education categories. For the period 2015–2100, a number of alternative scenarios have been calculated following the SSP narratives. This Wittgenstein Centre data set thus offers the world's most comprehensive harmonized dataset on national populations by age, sex, and educational attainment, with data being consistent across time, cohorts, and countries. The data can be downloaded from the Wittgenstein Centre Data Explorer (http://www.wittgensteincentre.org/dataexplorer). An update will be published in 2023.

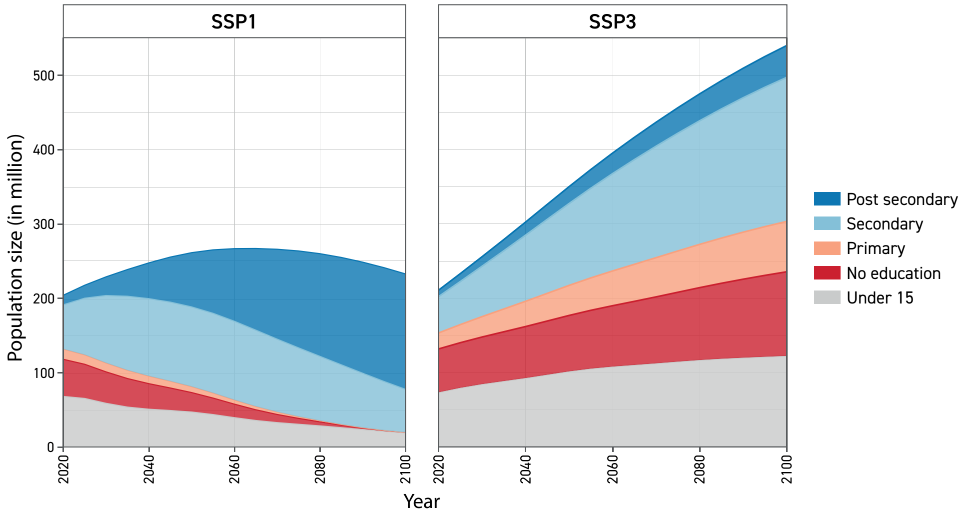
Example: Pakistan at the cross-roads—Contrasting the rapid development scenario SSP1 with the stalled development scenario SSP3[41]

According to a UNESCO assessment, Pakistan has some of the worst education indicators globally and the second-highest number of children not attending school, two-thirds of them girls.[42] Particularly alarming, according to UNESCO, is the situation in rural areas, especially in the northern and western provinces, where girls face substantial social and economic barriers. Consequently, 92–97% of rural adult women are illiterate. Pakistan has almost the highest population growth in Asia. Since its independence in 1947, the number of inhabitants has increased from 38 to 235 million.

At the same time, birth rates in Pakistan are still quite high by Asian standards with an average of 3.6 children per woman. Uneducated women have 4.2 children, while women with a university degree have an average of 2.6 children.[43] The future of Pakistan, as with most developing countries, thus largely depends on the further expansion of education, in particular among women. Being a divided country in education terms, the high-fertility, low-educated parts of the country will grow very rapidly, if education stalls, and gain an increasing proportion of the total population. This interaction between high fertility and low education would result, under the SSP3 scenario, in the population with no formal education at all actually increasing in size. This predicament is not, however, inevitable. According to the SSP1 scenario, strong efforts in education and social development would result in Pakistan's education structure coming to resemble that of industrialized countries over the second half of this century.

Figure 2.5. **Population in Pakistan by level of education for scenarios SSP1 (rapid social development) and SSP3 (stalled development)**

	2020	2050-SSP1	2050-SSP3	2100-SSP1	2100-SSP3
Population in million	209	264	350	235	540

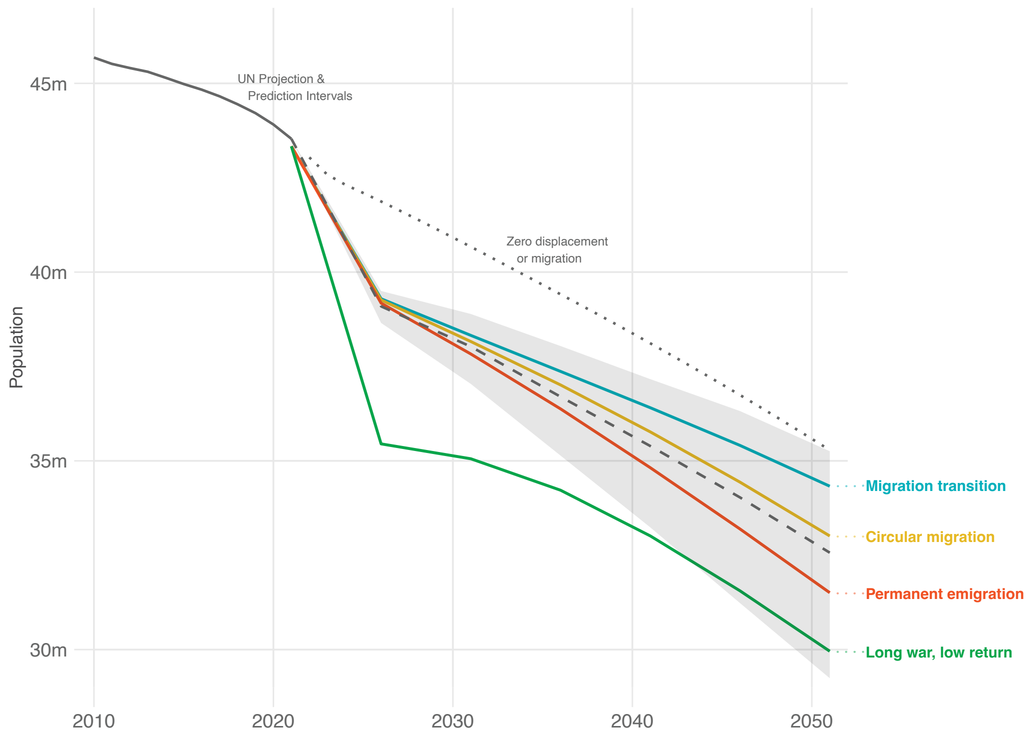


Note. Source: Wittgenstein Centre Data Explorer (2018).[36]

2.2 Way forward

The world is uncertain, and crises are multiplying. IIASA research must be anticipative as well as reactive, as it was when the COVID-19 pandemic hit the world—with consequences for fertility, mortality, urbanization, international migration, and human capital.[44,45] Or as it was when the war in Ukraine, which has displaced millions of people inside and outside the country (see Figure 2.6 which looks at different scenarios about the length of the war and the return rate of displaced people),[46] rocked the global food and energy markets and gave rise to seismic geopolitical developments. Demographic uncertainties will have to be studied and accounted for in the models: for example, the life span of humans and whether there is a limit or not to life expectancy. The same relates (in reverse) to fertility and how low it can get, given that women in some East Asian societies are having on average less than one child. Migration, always the most volatile of the demographic components of demographic change, will not go away. Quite the opposite, it will likely increase in importance, as inequalities increase and climate change puts additional stress on livelihoods, particularly in the poorest countries, while the developed world ages (see Box 2.3). Equity and justice are increasingly recognized as crucial principles for achieving global change to address global challenges in a fair and inclusive manner (see Section 6.2). In this field, research on equity will be needed to increasingly tackle poverty alleviation and the equitable distribution of wealth and resources—equity in education and healthcare, climate justice, and achieving equity in climate action, among others.[47]

Figure 2.6. **Scenarios of the population size of Ukraine depending on international displacement, return migration, and longer-term migration trends, 2020 to 2050**



Note. The graph shows five-year estimates starting from 2022. The first projection interval from 2022 to 2027 already includes a high number of refugees who have returned to Ukraine. The shaded area shows the 95% prediction interval around the UN median projection. The dotted line shows a projection with displacement and migration set to zero. Source: Ueffing et al. (2023).[46] Copyright 2023 by European Union.

As well as actions at the global and national level, the local context will become more relevant. In the field of population projections, IIASA has grasped the large implications of taking into account population dynamics at the subnational level (see for example, KC et al.[48]). Environmental change, too, can take many forms at the local level, including deforestation, land degradation, water pollution, soil erosion, loss of biodiversity, and climate change impacts such as sea-level rise, floods, and droughts, with substantial impacts on the population living in these areas. Further studies of climate-related migration and other impacts will be essential;[49,50] the Migration and Sustainable Development (MIG) group has already gained expertise in the analysis of complex drivers of migration.[51–56] Depopulation in high-income countries is also context-specific and more studies are required on the reasons for it (economic changes, cultural shifts, environmental factors, and life-cycle trends) and its consequences.

The issue of population heterogeneity will likely increase in importance. This is because it is becoming increasingly apparent that the conventional assumptions of homogeneity and representative agents typically used in demographic and economic modeling, represent an oversimplification that can have misleading results. While this insight goes back to the early years of the IIASA Population Program and the work by Vaupel and Yashin on *Heterogeneity's Ruses*,[57] there is still much to be done to account for these insights, not least in many of the IIASA models used in the energy and environmental fields. The multidimensional demographic approaches that account for such heterogeneity can be conducted either at the macro level by further subdividing categories (multi-state) or by using micro-simulation/agent-based models, which simulate individual behavior and decision-making. IIASA research has started using these in different applications. These models can be extremely complex and computationally intensive, however, and their feasibility depends on the specific research question being addressed and the data and resources available for the modeling exercise. Other tools such as machine learning and analysis of big data can help complete the picture.

For future IIASA work in the field of population and human capital analysis, irrespective of methodological innovations, intensive cooperation with the other substantive programs of IIASA will be essential to foster new cross-disciplinary research applications. This is the comparative advantage of IIASA over most of the other research institutions in the population field. Population research at IIASA is being inspired by scientific questions and approaches in other disciplines; not only that, it is also contributing powerful new multidimensional demographic approaches that are helping to improve the models and policy conclusions in other areas of scientific endeavor.

Box 2.6. Estimating global migration flows

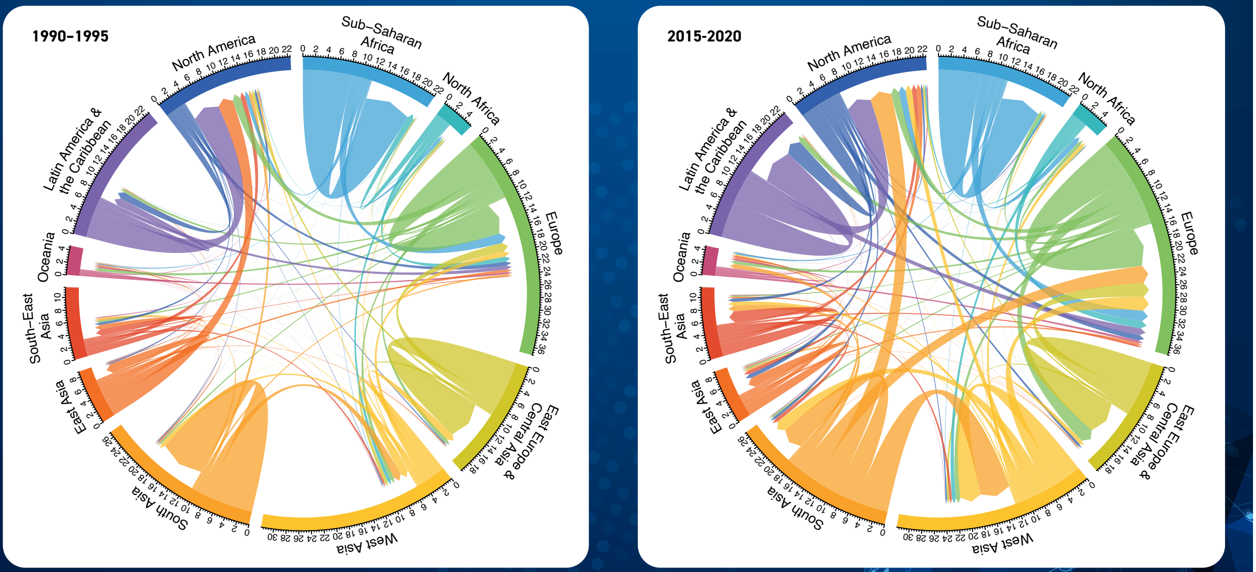
By Guy Abel

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

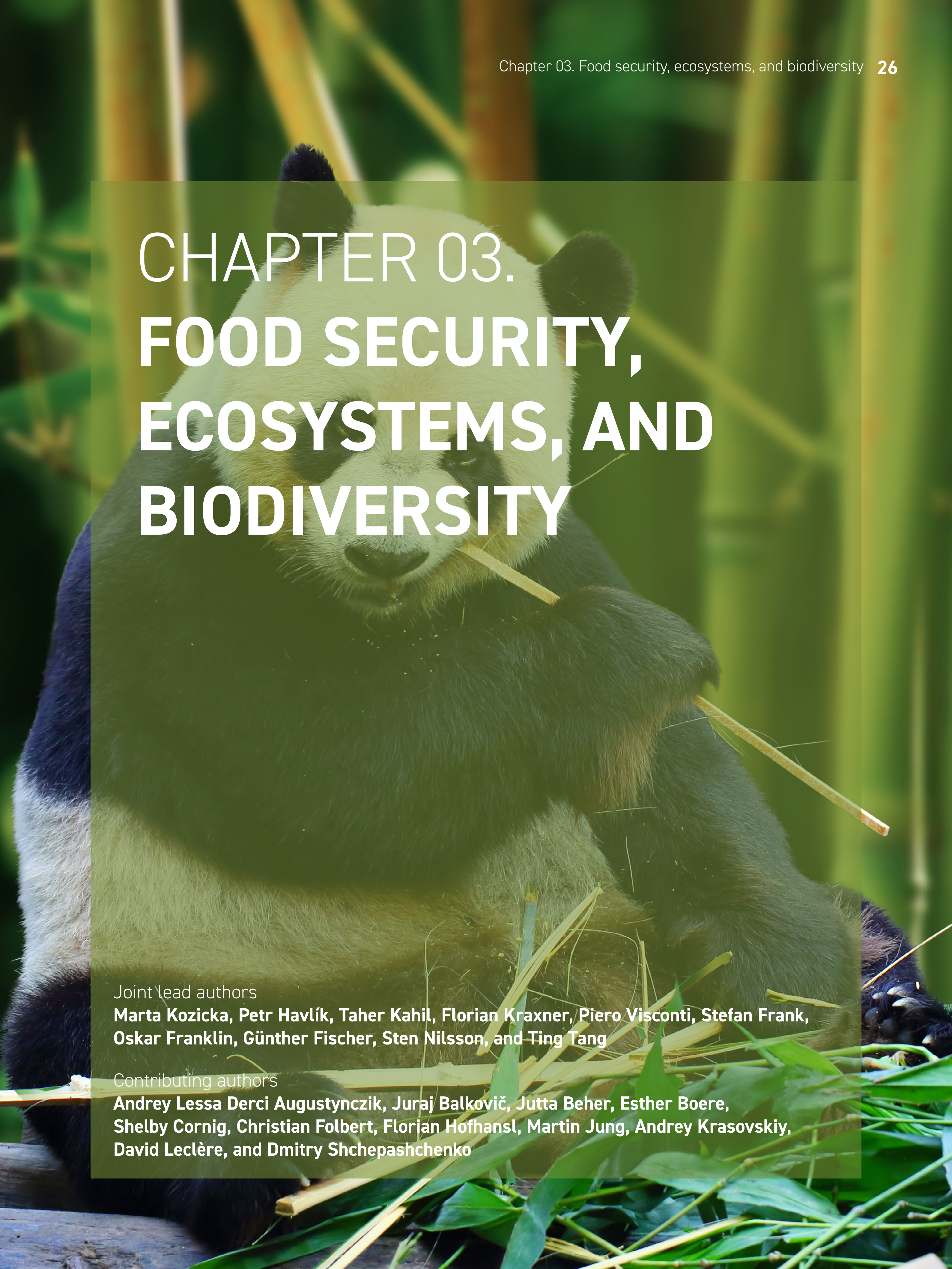
While estimated global migration flows generally increase over time, the percentage of the global population that migrates remains fairly steady at 0.65% of the global population over each five-year period.[58] This result supports similar findings in the migration literature on the lack of empirical evidence for an acceleration in global international migration, and suggests a shift in the directions of flows linked to major geopolitical and economic shifts.

The bilateral estimates quantify trends in global international migration flows over the past 55 years for the first time. Traditional migration-receiving countries such as Australia, Canada, New Zealand, and the USA, have seen almost continuously increasing numbers of migrants arriving. More recent growth is evident in countries in northern, southern, and western Europe, while a growing number of migration flows were estimated along migrant corridors between countries in South Asia (such as Bangladesh, India, and Pakistan) to West Asia (such as Qatar, Saudi Arabia, and the United Arab Emirates), and from Asia to North America. Large migrant transitions have also been estimated in selected periods within Africa or Eastern Europe during times of armed conflict or political change.[58] Female shares of global migration flows were found to have decreased from 1990–1995 to 2005–2010 followed by a recovery over the decade since 2010 toward parity.[59] The latest updates of estimated bilateral flows can be viewed and downloaded from the Global Migration Data Explorer (https://global-migration.iiasa.ac.at/).

Figure 2.7. **Migration flows 1990-1995 and 2015–2020**



Note. Estimated migration flows using the closed psuedo Bayesian demographic accounting method. Source: Abel and Cohen (2019).[58] Reprinted under the terms of the Creative Commons Attribution 4.0 International License.



CHAPTER 03.

FOOD SECURITY, ECOSYSTEMS, AND BIODIVERSITY

Joint lead authors
Marta Kozicka, Petr Havlík, Taher Kahil, Florian Kraxner, Piero Visconti, Stefan Frank, Oskar Franklin, Günther Fischer, Sten Nilsson, and Ting Tang

Contributing authors
Andrey Lessa Derci Augustynczik, Juraj Balkovič, Jutta Beher, Esther Boere, Shelby Cornig, Christian Folbert, Florian Hofhansl, Martin Jung, Andrey Krasovskiy, David Leclère, and Dmitry Shchepashchenko

3.1 Background and past achievements

Throughout history, food security has been a central concern of individuals and societies. The right to food has, in fact, been recognized as a basic human right by the United Nations. Many agencies have been created at the national and international level to address this issue, but humanity has been unable to resolve the problem of hunger—despite the global consensus on eliminating hunger, the well-intentioned actions of individuals, organizations, and governments over the years, and the progress made in modern science and technology. Although hunger tends to be a regional problem, the growing interdependence of the various parts of the global food system now demands an international approach. Moreover, feeding a growing population with ever-dwindling resources foreshadows worsening poverty and hunger; the complex and interconnected challenges involved, such as environmental degradation, biodiversity loss, and climate change, must be addressed by computer-based modeling efforts of the type developed and deployed at IIASA (see Box 3.1).

IIASA's first contribution to this field was a system of coupled national and regional models, each with distinct agricultural policy, production, consumption, and trade components that together formed a world food system model, eventually termed the Basic Linked System (BLS). BLS is an early example of advanced systems analysis at IIASA—it was the first global multi-region and multi-commodity applied general equilibrium model of the world food system.[1]

As an initial application, this IIASA world food system model addressed two policy issues. The first was trade liberalization, seen by some as a means of mitigating food insecurity. For this, IIASA undertook an in-depth analysis of the impacts and also of the winners and losers of trade liberalization in agriculture.[2] The second was a variety of policy measures proposed to eliminate hunger, the effectiveness of which was analyzed by IIASA.[3] These analyses showed that in the business-as-usual scenario, hunger and poverty would not be eradicated over the coming decades, even if the world economy were to exhibit sustained growth. Some policy alternatives for developing countries, it was found, could reduce hunger more rapidly, but these would either slow overall economic growth or require substantially larger external aid flows. Trade liberalization, for example, combined with liberalized international movement of labor and other production factors, plus additional aid to finance redistributive programs in poor developing countries, could rapidly eradicate hunger. Several applications of the BLS to climate-change impact analysis followed in the 1990s and were widely published.[4–6]

The Malthusian fear that population growth could outpace the ability of agriculture to supply adequate food resources, in spite of the speed of technological progress, motivated the Food and Agriculture Organization (FAO) of the United Nations to devote considerable attention to the development of techniques for resource inventory evaluation and planning, both at continental scale and through its field programs in developing regions and individual countries. In collaboration with IIASA, FAO developed a system for rational land use planning based on a spatially detailed inventory of land resources, referred to as Agro-ecological Zoning (AEZ). During 1976–1981, the first AEZ Project was an early exercise in the application of land evaluation at a continental scale. The methodology used was innovative in that it characterized tracts of land using quantified information on climate, soils, and other physical factors to predict the potential productivity for various crops according to their specific environmental and management needs. The AEZ model was also the basis for the influential FAO/IIASA/UN Population Fund (UNFPA) land-carrying capacity study which was a milestone in assessing resource limitations and identifying regions where self-reliance in food supply was problematic or impossible.[7] The completion of the Digital Soil Map of the World in 1995 marked the start of the global application of AEZ and the development and public release of global AEZ data products and analysis. With the launch of the GAEZ v4 Data Portal by FAO in 2021, a GAEZ community was established to foster collaboration among GAEZ users, co-develop directions of future updates and improvements, and provide information about new data releases and methodological updates. Agriculture perspective and scenario studies still rely on AEZ data and national and global assessment results to address the heterogeneity of agricultural production conditions and identify geophysical limitations. FAO agricultural perspective studies[8–11] have made significant reference to the GAEZ database regarding the use and availability of natural resources and the impacts of climate change on crop production and food systems.

The combination of AEZ and BLS constituted an advanced integrated ecological–economic framework, which has been applied in several major IIASA studies. In a special report submitted to the World Summit on Sustainable Development, Johannesburg 2002, the sensitivity of agro-ecosystems to climate change, as determined by the AEZ model, was assessed by the BLS model within the socioeconomic scenarios defined by the Intergovernmental Panel on Climate Change Special Report on Emissions (IPCC SRES).[12] The conclusions of this seminal report are still valid today.

IIASA is also at the forefront of ecosystems research. The foundations of the theory of ecosystem resilience—the amount of disturbance that an ecosystem can withstand without changing self-organized processes and structures (defined as alternative stable states)—were formulated at IIASA by Director Crawford Holling in the 1970s.[13] This work is still at the center of concern in forestry today, as researchers investigate how to shape resilient forest ecosystems, given the high pressure on forest resources, climate change, and rapidly declining biodiversity.

During 1980–1985 a major forest project operated at IIASA, the objective of which was to analyze, from a systems perspective, the big picture of the forest sector: forest resources, forest management, ecosystem management, wildlife management, fire management, and forest products industry, markets, and demand. The main output of one objective, to link national, regional, and global interactions, was a Global Forest Sector Model,[14,15] the first of its kind and a role model for later efforts in this kind of modeling. Some of the scientists involved were honored with the Markus Wallenberg Prize in 2023, the highest international award in forestry.

In the 1980s the IIASA Forestry Program established the first independent and consistent forest database encompassing all of Europe, which constituted the basis for many later databases of a similar kind. The simulation model used for analyses of the database is still in use (but at a further- developed stage) by the European Forest Institute and University of Wageningen, and is often used in connection with European Union (EU) and United Nations (UN) policy analysis.[16] In the early 1990s the IIASA Forestry Program expanded its area of investigation to Siberia and was able to gain access to and validate datasets of the Siberian forest ecosystems through its network of Russian institutions. It was the first time such information was made available outside Russia, and the international interest in the information was tremendous.[17] Around the same time a groundbreaking assessment of the impact of a possible global afforestation program was published.[18]

In the early 2000s IIASA's Forestry Program hosted a pathbreaking remote sensing analysis of the Russian forest ecosystems, including ground validation of the remotely sensed data. The studies made it possible to identify the strengths and weaknesses of remotely sensed data for large-scale analysis.[19] In addition, an analysis of the forest resources in China was carried out, presenting the first holistic assessment of the country's forest resources to the international community and revealing the weaknesses of the Chinese data. This study also opened the door to later cooperation on forestry and the forest sector in China.[20]

Box 3.1. Early food system research at IIASA*

As mentioned in Chapter 5.1, IIASA's establishment in 1972 coincided with the publication of the first two reports by the Club of Rome. The first, by Jay Forrester from MIT, was called *World Dynamics*[21] and the second, by Dennis Meadows and his MIT team, *The Limits to Growth*.[22] Feeding the rapidly increasing world population with limited resources was a key concern of these studies.

After the Forrester and the Meadows reports had been published, IIASA was still in its infancy and in many ways connected to the Club of Rome, which had lobbied for its creation. It had several Club of Rome members on its governing council, notably council chair, Yermen Gvishiani, son-in-law of Soviet Prime Minister Kosygin, and Gerhart Bruckmann from Austria, who helped IIASA settle in Laxenburg and also showed keen interest in global modeling. This connection explains why, in 1972, IIASA requested Tjalling Koopmans, a highly reputed Professor of Economics at the Cowles Foundation at Yale, to organize a series of annual Global Modeling conferences dedicated to Club of Rome–related studies.

In the same year the Club of Rome requested Nobel Prize laureate, Jan Tinbergen, and his former student and colleague, development economist, Hans Linnemann, to conduct a follow-up study on the problems resulting from a "doubling of world population," which relative to 1975, was expected to be reached around 2010. At that time, the Club of Rome considered population growth to be the primary threat to the future of humankind. The study, however, placed particular emphasis on poverty and hunger, in 1975 delivering a Model of International Relations in Agriculture (MOIRA).[23]

Tjalling Koopmans had been closely associated for many years with the MOIRA patron, Jan Tinbergen. At IIASA's Third Global Modeling Conference, the MOIRA team presented its findings which, unlike the Malthusian emphasis on demographic pressure put forward by the Club of Rome, highlighted poverty as the central problem. During this Conference, Hungarian Professor Ferenc Rabar approached the MOIRA team, mentioning that IIASA Director Roger Levien had asked him to think about future global modeling projects at the institute. This sequence of events led to the establishment of a Food and Agriculture Program (FAP) at IIASA in 1976 and marked the beginning of a long, intense, and fruitful collaboration with the Amsterdam-based Centre for World Food Studies and the UN Food and Agriculture Organization in Rome.

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*Based on contributions by Günther Fischer

3.2 Current situation

Across the resource spectrum, whether related to food, forests, biodiversity or water, the fears of imminent catastrophe of the early 1970s have not materialized. Nevertheless, fears of catastrophe do persist and, especially with the acceleration of climate change effects, are credible.

Food systems

Agricultural technology and practices, infrastructure improvements, and trade expansion have contributed to the increase in food availability. In particular, the Green Revolution in the 1960s and the 1970s resulted in the widespread adoption of high-yielding crop varieties, improved irrigation techniques, and increased use of fertilizers and pesticides.[24] This resulted in a gradual decline and eventual stabilization of food prices in real terms until the mid-2000s. Hunger and malnutrition have declined, with the prevalence of undernourishment globally falling from 12.4% in 2005 to 8.1% in 2017.[25]

Despite past progress, the trifecta of conflict, climate extremes, and COVID-19 effects have been disrupting food systems and worsening food security in many countries in recent years, reversing over a decade of progress against hunger.[26] Since 2018 both the prevalence and the absolute number of undernourished people globally have been increasing, reaching up to 828 million people and 10.5% of the world population in 2021.[27] Following decades of steady productivity increases, there are signs that the limits of the green revolution have been reached in some places.[28] Increased frequency and intensity of weather extremes due to climate change[29–31] will likely continue to increase yield variations[32–34] and food production losses.[30] Simultaneously, changing lifestyles and dietary patterns ("westernization" of diets) characterized by high consumption of meat and processed foods, have led to an increase in overweight and obesity.[35] Unsustainable diets have also negatively impacted the environment and exacerbated climate change due to high natural resource use and greenhouse gas (GHG) emissions.[36]

Box 3.2. Food security*

Increasing food production through agricultural land intensification and extensification is one of the approaches to meeting the dietary needs of a growing world population. Agricultural production, however, requires the use of chemical inputs and consumes natural resources, both of which can negatively impact the environment. Ending hunger while achieving other targets of global sustainability thus requires innovative solutions. IIASA researchers together with colleagues from Japan enhanced the IIASA global agricultural and forest sector model, GLOBIOM,[38] (see below) by approximating the food availability distribution across individuals within the population to study reduction in the inequalities in access to food as an alternative strategy to increasing agricultural production; the goal was to potentially reduce the apparent conflict between food security and environmental sustainability. The researchers found that if hunger eradication is achieved by 2030 through a general increase in food availability (Figure 3.1a), typically associated with sustained economic growth without additional food security policies, a 20% increase in food production would be required compared to the business-as-usual scenario. This would, in turn, require 48 Mha of additional agricultural land and also increase greenhouse gas emissions by 550 Mt CO2eq/year in 2030. The alternative strategy focuses exclusively on bridging the nutritional gap of the

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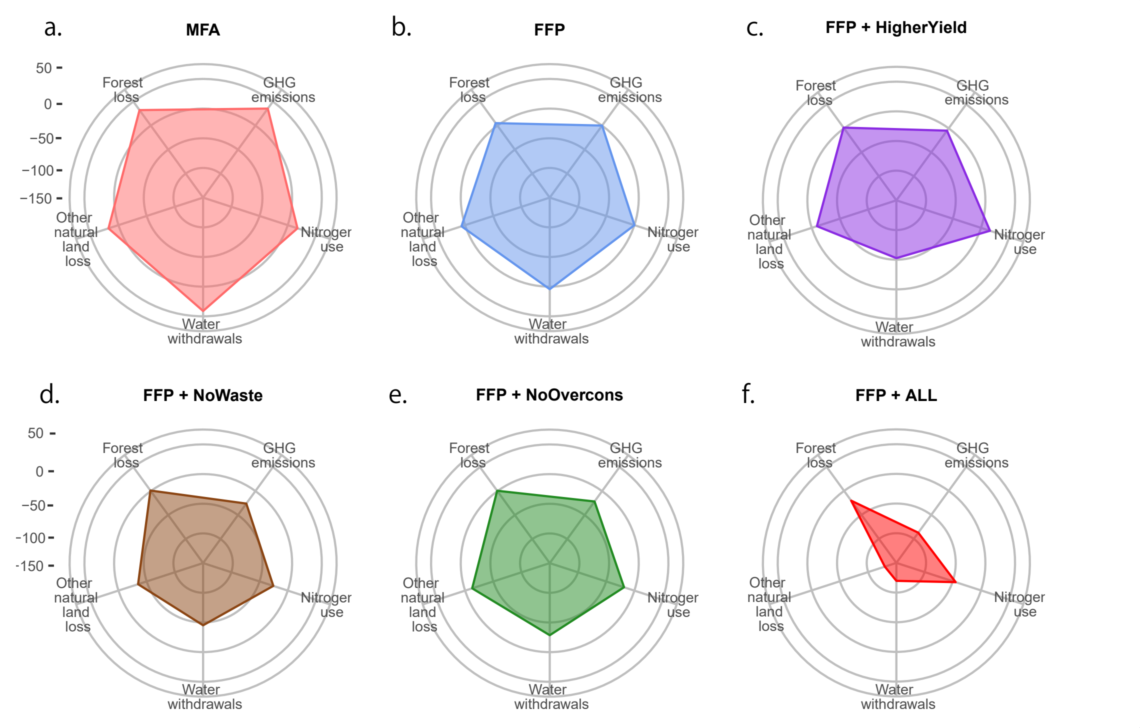
*Based on Hasegawa et al. (2019).[37]

undernourished population, which could be delivered through targeted food security interventions, such as in-kind food transfers or school-feeding programs. In this scenario, in order to eradicate hunger by 2030, food production would only need to increase by 3%, with a correspondingly limited increase in the negative effects on the environment (Figure 3.1b). Finally, if equity of food distribution is accompanied by a reduction in over-consumption and food waste, as well as improved agricultural productivity, undernutrition can be eradicated and at the same time agricultural production reduced (by 9%), leading to multiple benefits for environmental sustainability (Figure 3.1f).

Figure 3.1. **Global agricultural impacts on the environment under different hunger eradication policies in 2030**



Note. a. More Food for All (MFA); b. Food for the Poor (FFP); c. FFP + HigherYield; d. FFP + NoWaste; e. FFP + NoOvercons; f. FFP + ALL. Indicators show agricultural irrigation water withdrawals, nitrogen fertilizer use, GHG emissions from agriculture and land use, forest area loss, and other natural land loss. The rings indicate the difference (%) between the changes for each indicator in 2030 relative to 2010 and those in the baseline scenario with no hunger policy. Source: Hasegawa et al. (2019).[37]

Food and environmental sustainability

As concerns shifted from food security and the economic profitability of farm enterprises to broader environmental sustainability, IIASA researchers developed the Global Biosphere Management Model (GLOBIOM).[38–41] GLOBIOM (see Box 3.3) represents in an integrated way the agricultural and forestry sectors; it is built following a bottom-up setting based on detailed grid cell information that provides biophysical and technical cost information. Over its short history, GLOBIOM has been used in numerous academic studies, in many national and international policy and regulatory processes, as well as in foresight initiatives, several of them highlighted in this chapter. The model is continuously improved to allow decision-makers to design solutions for sustainable management of land and water resources that also satisfy human needs.

Future scenarios developed at IIASA, both global (e.g., SSP2 marker implementation)[42] and regional (e.g., West African food and climate futures developed jointly with the Consultative Group on International Agricultural Research [CGIAR]),[43] have been widely used by the global research community to study the future development of food systems. IIASA has significantly contributed[44] to the growing evidence that further increases in food demand due to economic and population growth, continued westernization of diets, and the expected negative impacts of climate change on agricultural productivity, will increase pressures simultaneously on food security, health, climate, and ecosystems.[45–47] IIASA has been a leader in mapping and quantifying synergies and trade-offs between achieving food security and other global goals, such as other Sustainable Development Goals (SDGs),[48] biodiversity targets,[45,49] and climate mitigation goals.[48,50–52] The studies show that adoption of a mainly plant-based diet will be an important component of strategies to meet these different goals. Novel meat and milk analogues that closely resemble animal-sourced foods are considered as one of the innovations that could accelerate the transition toward a sustainable food system.[53] IIASA researchers demonstrated in a collaborative study[54] that a partial adoption of plant-based meat and milk alternatives could serve multiple environmental and climate goals. Furthermore, IIASA research has found that reduction in trade tariffs and agricultural development combined with environmental and social safeguards are also measures that could promote food security at little or no environmental cost.[55,56] Policies and interventions that improve food distribution, reducing over-consumption and waste while increasing consumption of the under-nourished, could significantly reduce food demand and hence lead to the multiple benefits involved in combating hunger and contributing to environmental sustainability (Box 3.3).[37]

Box 3.3. Focus on livestock modeling*

Livestock provides numerous important services, such as nutrition, traction, manure, risk management, and regular income.[57–59] At the same time, it is at the center of many sustainability challenges, such as being a major driver of land use change[60] and the main source of agricultural non-CO2 emissions.[61] Nevertheless, livestock sector representation in the global agricultural sector models was at one time very simplistic, often completely ignoring the link to grasslands and the heterogeneity across livestock production systems. IIASA researchers engaged in a close collaboration with the CGIAR International Livestock Research Institute (ILRI) to develop a unique, biologically consistent, spatially disaggregated global livestock dataset containing information on biomass use, production, feed efficiency, excretion, and greenhouse gas emissions for 28 regions, 8 livestock production systems, 4 animal species (cattle, small ruminants, pigs, and poultry), and 3 livestock products (milk, meat, and eggs).[62] This key dataset was at the core of a new livestock representation in the GLOBIOM model.[38] The inaugural study shows that, by 2030, autonomous transitions toward more efficient livestock production systems would decrease GHG emissions by 736 million metric tons of carbon dioxide equivalent per year (MtCO2e·y−1), mainly through avoided emissions from the conversion of 162 Mha of natural land. A moderate mitigation policy targeting emissions from both the agricultural and land use change sectors with a carbon price of US$10 per tCO2e could lead to an abatement of 3,223 MtCO2e·y−1. Livestock system transitions would contribute 21% of the total abatement, intra- and interregional relocation of livestock production another 40%, and all other

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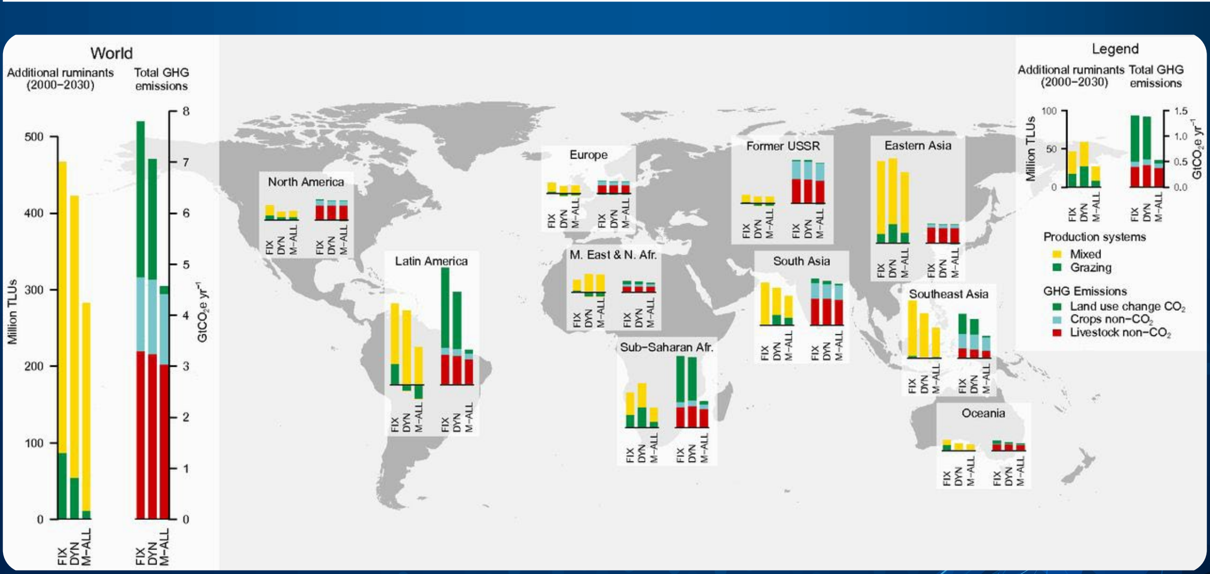
*Based on Havlík et al. (2014). [38]

mechanisms would add 39%. The study also showed that mitigation policies targeting emissions from land use change are 5 to 10 times more efficient—measured in "total abatement calorie cost"—than policies targeting emissions from livestock only.

The new dataset allowed an explosion in sustainability assessments of the livestock sector across the world, and was also adopted by economic models other than GLOBIOM, including the CGIAR IFPRI IMPACT model.[63] On the other hand, the inclusion of the livestock component in GLOBIOM allowed for countless studies, including the first ever global climate change impacts assessment with a focus on livestock[64] and the assessment of African livestock futures.[65]

Figure 3.2. **Change in ruminant numbers from 2000 to 2030 and total annual GHG emissions from agriculture and land use change**



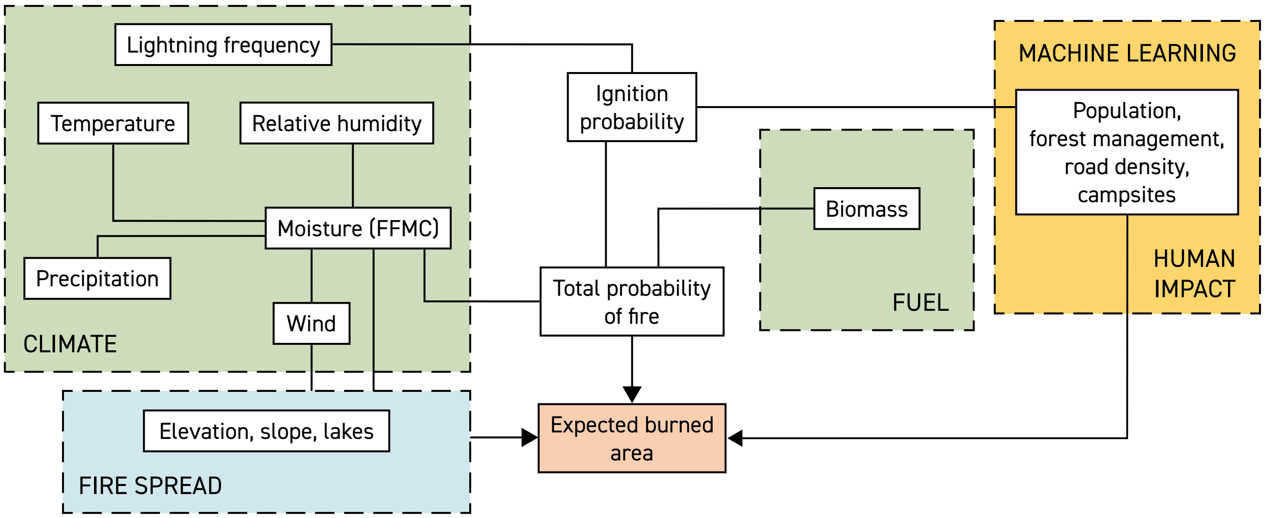
Note. FIX – Fixed production systems scenario with livestock production systems structure kept constant over the simulation period, DYN – Dynamic production systems scenario with autonomous transitions across the production systems following market signals, M-ALL – Mitigation scenario with dynamic production systems and a carbon price of US$10 per tCO2e applied to emissions from both agricultural and land use change sectors. Y-axis scales are the same in all graphs. TLU, tropical livestock unit (i.e., an adult animal of 250 kg weight). Source: Havlík et al. (2014).[38]

Land use and forestry

The land use sector, in particular forestry, is an important source of biomass for material and energy purposes, and global timber harvesting is projected to continue to increase in the next decades.[66,67] Over the last two decades woody biomass has increasingly been used to produce renewable energy, partly as a solution to climate change mitigation. Modern bioenergy use has been increasing on average by about 7% per year between 2010 and 2021, and currently accounts for 55% of renewable energy and over 6% of global energy supply. IIASA's GLOBIOM and G4M models have been applied to assess the implications of increased competition for biomass feedstocks and related sustainability concerns.[51,67,68] IIASA researchers participated in studies assessing the impacts of biofuel consumption on land use change and GHG emissions.[39,69–72] This work contributes to IIASA's ongoing support to the European Commission, providing Indirect Land Use Change (ILUC) estimations related to the International Civil Aviation Organization's approach to reducing emissions from international aviation, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Using the Wildfire Climate Impacts and Adaptation Model (FLAM, see Figure 3.3), IIASA researchers have conducted a comprehensive analysis of the growing and changing threat of wildland fires worldwide as a result of climate change. FLAM is modular and includes four main variable types: climate, topography (fire spread), fuel, and human impacts. Its modular nature allows researchers to adjust climate data based on different warming and climate change scenarios or on the compounding effects of climate change on normal weather phenomena such as El Niño Southern Oscillation (ENSO) events. Additional variables relevant to the region, such as agricultural or peatland burning practices, road density, fire response agency locations and response times, and forest management and conservation strategies can also be included. Case studies in European countries[73–75] as well as in South Korea[76] and Indonesia[77,78] highlight a clear trend of increased burned area under all climate change scenarios, with more extreme scenarios resulting in more burned area. Without climate adaptation and wildfire mitigation measures, global burned areas could increase by as much as 200% by 2100.[79] These results align with international analyses indicating that climate change is likely to increase the frequency and impact of wildland fires in various regions of the world.[80]

Figure 3.3. **Wildfire Climate Impacts and Adaptation Model (FLAM) scheme**



Note. Source: www.iiasa.ac.at/flam. Copyright by IIASA/Andrey Krasovskiy.

To try to keep global warming below 1.5 °C and mitigate the adverse effects of climate change, the land use sector, like all other sectors, must contribute to efforts to achieve net negative emissions by the end of the century. IIASA researchers participated in various studies assessing Agriculture, Forestry and Other Land Use (AFOLU) abatement contributions (Box 3.4), which are currently estimated at 6.8–8 GtCO2eq/yr of GHG in 2050.[81]

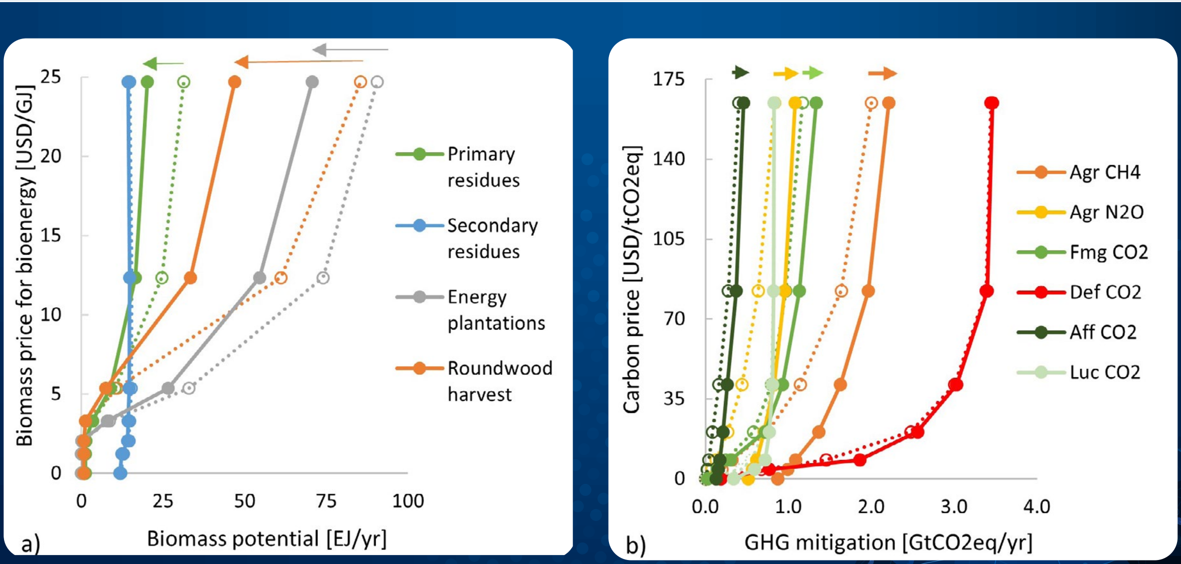
World soils, the third largest global carbon stock after the oceanic and geologic carbon pools, are central to climate change mitigation and carbon–climate feedbacks.[82] Several approaches and practices that promote soil carbon sequestration can provide cost-effective climate mitigation options. These include, among others: agroecology, conservation measures, agroforestry, and some integrated animal and crop production systems; restoration of degraded forests, rangelands, and wetlands; and measures to enhance soil carbon storage in managed landscapes, such as reduced or no-till farming practices, cover crops, green manures, and intercropping.[83–85] IIASA research[86] has found that carbon sequestration in soils could compensate for 7% of total emissions from agriculture within the EU, 10% if co-benefits from the crop and livestock sector are included. Another study[50] showed that increasing soil carbon sequestration on agricultural land would allow a reduction in the negative impacts of climate change mitigation on agricultural production and food security (Box 3.4).

Box 3.4. Climate stabilization, including soils* and soil carbon potential (EPIC)

By Stefan Frank and Juraj Balkovič

The mitigation of CO2 emissions and the sequestration of carbon in managed and newly established forests is considered one of the most important low-cost mitigation options. Reducing CO2 emissions from deforestation is considered to be cost-effective at carbon prices <50 USD/tCO2,[87] while mitigating agricultural non-CO2 emissions becomes more important at higher carbon prices.[38,88] Achieving the land use–related SDGs could lead to even deeper emissions cuts and contribute 25% of the expected AFOLU contribution to the 1.5°C target, mainly through reduced consumption of animal products, decreased food waste, and biodiversity protection.[51] Soil carbon storage sequestration on crop and grassland is recognized as a valuable negative emission technology that offers both emissions savings and benefits for food security.[50] For example, the annual sequestration rates due to management practices in European cropland were estimated in the range of 0.1 to 0.5 t C ha-1.[89] Improving soil health and the provision of ecosystem services are also important strategies. Beyond the GHG savings, the land use sector is also an important source of biomass for bioenergy and fossil fuel substitution.[51,90 67]

Figure 3.4. **Sustainable land-based mitigation potentials**



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*Based on Frank et al. (2021). [51]

Note. (a) Global biomass potential for bioenergy by feedstock in EJ yr^{-1} in 2050 without carbon price. Biomass prices represent USD GJ^{-1} primary biomass used for bioenergy. (b) AFOLU marginal abatement cost curves in GtCO2eq yr^{-1} in 2050 at baseline bioenergy levels. Solid lines—considering SDGs, dotted lines—not considering SDGs (noSDGs). Agr CH4 (methane from rice cultivation, enteric fermentation, and manure management), Agr N2O (nitrous oxide emissions from synthetic fertilizer and manure application, manure dropped on pastures, and manure management), Fmg CO2 (carbon dioxide emissions/removals from forest management), Aff CO2 (carbon dioxide emissions/removals from afforestation), Def CO2 (carbon dioxide emissions from deforestation), Luc CO2 (carbon dioxide emissions/removals from other land use changes). Source: Frank et al. (2021).[51] Reprinted under the terms of the Creative Commons Attribution 4.0 International License.

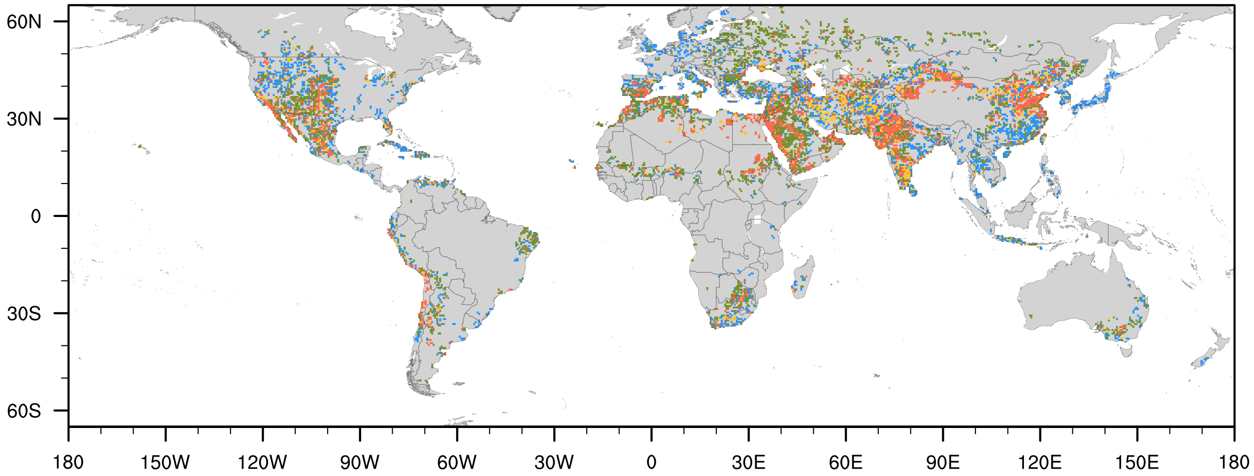
Fresh water

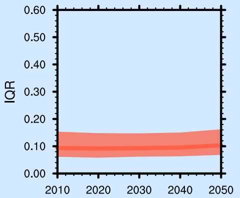
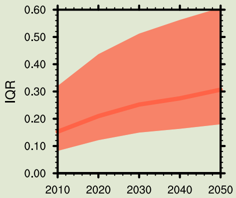
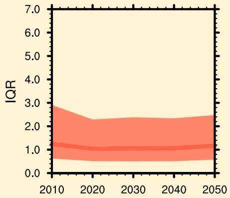
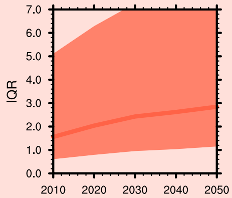
Global water withdrawal for irrigation and expanded drinking water supply increased by 15% per decade between 1960 and 2010. Agriculture is the principal water user, accounting for 70% of total withdrawals, with the rest destined for the industrial and domestic sectors.[91] The socioeconomic benefits of withdrawals for food security and poverty alleviation have, however, heightened water scarcity, reduced water quality, and increased ecosystem vulnerability and degradation in many world regions.[92] Excessive nutrients and salinity in the water exacerbate water scarcity, reducing sectoral water supply and increasing water treatment costs.[93] These challenges are expected to grow as countries attempt to sustain a larger and more prosperous human population and economy under changing climate conditions.

Projections by the Water Futures and Solutions (WFaS) Initiative of IIASA show a consistent increase (20–33%) in global water demand by 2050 across various future climate and socioeconomic scenarios. A collaborative global effort, the WFaS initiative develops systems analysis–based scientific evidence and tools to identify water-related policies and management practices that work coherently across scales and sectors to improve human wellbeing through enhanced water security. Within WFaS, and in collaboration with a group of water planners and stakeholders from around the world, the storylines of the Shared Socioeconomic Pathways (SSPs) were extended by relevant critical dimensions affecting water availability and use. These dimensions were assessed qualitatively and quantitatively for each SSP and group of countries based on a two-dimensional hydro-economic (HE) classification system. These provided a first set of global water scenarios[94] which were applied to three global hydrological models to provide the first multi-model analysis of global water use for the 21st century.[95] Using the WFaS projections, the global water challenges arising from the anticipated median changes in water scarcity conditions were assessed in combination with the associated uncertainty in water scarcity projections: a comprehensive and innovative policy framework was thus used (Figure 3.5) as a basis for decision-making from regional to global scales.[96]

Subsequently, the WFaS approach was used to assess future water supply and demand to 2050 for the whole Asian continent. It showed socioeconomic changes to be the main drivers of growing water scarcity in Asia, with climate change impacts further increasing the challenge into the 21st century.[97] The WFaS approach was also downscaled to co-develop regional water scenarios for East Africa with local stakeholders. Scenarios were simulated using an integrated hydro-economic modeling framework combining the hydrological model CWatM and hydro-economic model ECHO to inform water planning and investment decisions in the extended Lake Victoria basin.[98]

Figure 3.5. **Areas of differing management challenges with respect to anticipated water scarcity conditions within the first half of the 21st century and potential policy actions and decision-making frameworks**



Challenges	low	medium	medium	high
median **water scarcity** (in 2050)	< 0.4 non-, slightly water scarce	< 0.4 non-, slightly water scarce	> 0.4 severely water scarce	> 0.4 severely water scarce
within-area **range of uncertainty** (2010-50)				
uncertainty (2010)	low IQR < 0.15	low to medium IQR < 0.35	medium to high IQR > 0.6	medium to high IQR > 0.6
uncertainty changes (2010-50)	relatively stable	medium to high increase	relatively stable	medium to high increase
Policy actions	monitoring and reviewing risks	transitional changes	transitional/ transformational changes	transformational changes
Decision-making frameworks	conventional approaches such as e.g., cost benefit analysis	iterative processes and robust-decision making		
		beginning with low-regret options	evaluating potential for both transitional and transformational options	evaluating transformational options

Note. Source: Greve et al. (2018).[96]

Biodiversity

Natural ecosystems have been lost at an average rate of 1% of their global extent per decade since 1970,[99] with some, such as coral reefs, being lost much faster (4% per decade). Recent trends do not fully reflect historical changes and natural baselines. Between 1700 and 2000, for example, 87% of global wetland extent was lost.[100] About 25% of species whose extinction risk is known, are in high extinction risk categories. Extinction rates are 100–1,000 times higher than the expected natural species turnover.[101] There is much evidence that loss of biodiversity would have been more severe in the last decades without conservation efforts.

Hoffmann et al.[102] assessed the cumulative extinction risk of species, measured through the Red List Index, would have been at least 18% worse for birds and mammals without conservation efforts in 1980–2008. This is equivalent to preventing 39 bird and 29 mammal species moving one category closer to extinction in the same period. Bolam et al.[103] found that conservation action prevented 21–32 bird and 7–16 mammal outright extinctions since 1993, and 9–18 bird and two to seven mammal extinctions since 2010. While 10 bird and five mammal species have gone extinct since 1993 (or are strongly suspected to have done so), extinction rates would have been 2.9–4.2 times greater without conservation measures. IIASA has contributed to development of methods to estimate the impact of conservation measures using population abundance time-series, a more sensitive measure of biodiversity trends at the species level. Analyzing data from 26,904 vertebrate populations across 4,629 species worldwide, and using statistical matching to assess the counterfactual population trends in the absence of conservation, a study[104] found that animal populations benefiting from conservation efforts had on average 102%–233% more positive population trends than populations that did not. The range depends on the stringency of the matching criteria in the treatment and control population being compared.

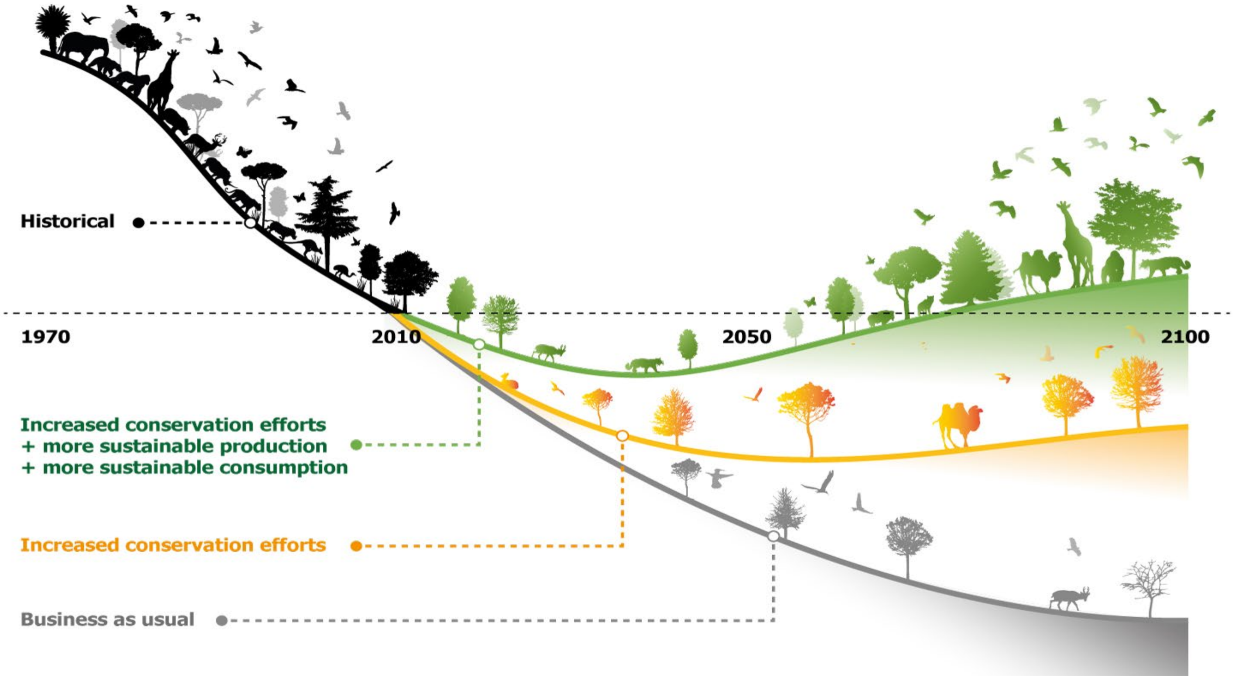
3.3 Way forward

While progress has been made in reducing and even eradicating hunger and extreme poverty, this has often happened at the expense of environmental degradation. Even though many countries are now actively pursuing environmental objectives, recent events, such as the COVID-19 pandemic and the Russian war in Ukraine, have reawakened awareness of the importance of energy and food security even where they seemed long forgotten. Against a background of increasingly frequent extreme weather events, however, public- and private-sector decision-makers are seeking holistic solutions, such as integrated systems analysis modeling techniques, that deliver simultaneously across all sustainability dimensions.

The challenges are too big to be solved by a sectoral solution, as demonstrated in a recent IIASA-led community effort bringing together four integrated assessment modeling teams and seven biodiversity modeling teams to analyze the feasibility and means of bending the curve of biodiversity loss.[45] The study found that conservation and restoration alone, though necessary, are insufficient, even at an ambitious scale (Figure 3.6). In one scenario, protected areas cover 40% of global land, and 5 million km^2 of degraded land are restored by 2050. In some models, this leads to global biodiversity trends starting to slowly improve around 2050. The constraints on land use would, however, cause a rise in global food prices, likely to undermine SDG 2 of zero hunger and undermine political acceptability. By contrast, tackling the drivers of habitat loss, improving food supply through trade and sustainable yield increases, and reducing demand through less food waste and a lower share of meat in diets, leads to biodiversity trends turning positive before 2050, without increasing food prices. The co-benefit for climate change mitigation is also substantial: relative to the conservation-/restoration-only scenario and averaged across models, it leads to a roughly 30% fall in greenhouse gas emissions from agriculture, forestry, and other land uses (which amount to just over 20% of all current GHG emissions).

The integrated action scenario also puts less strain on water resources and leads to healthier diets.

Figure 3.6. **Global land use pathways toward reversing global biodiversity loss, highlighting the need for integrated solutions**



Note. Artwork by Adam Islaam, based on Leclère et al. (2020).[45]

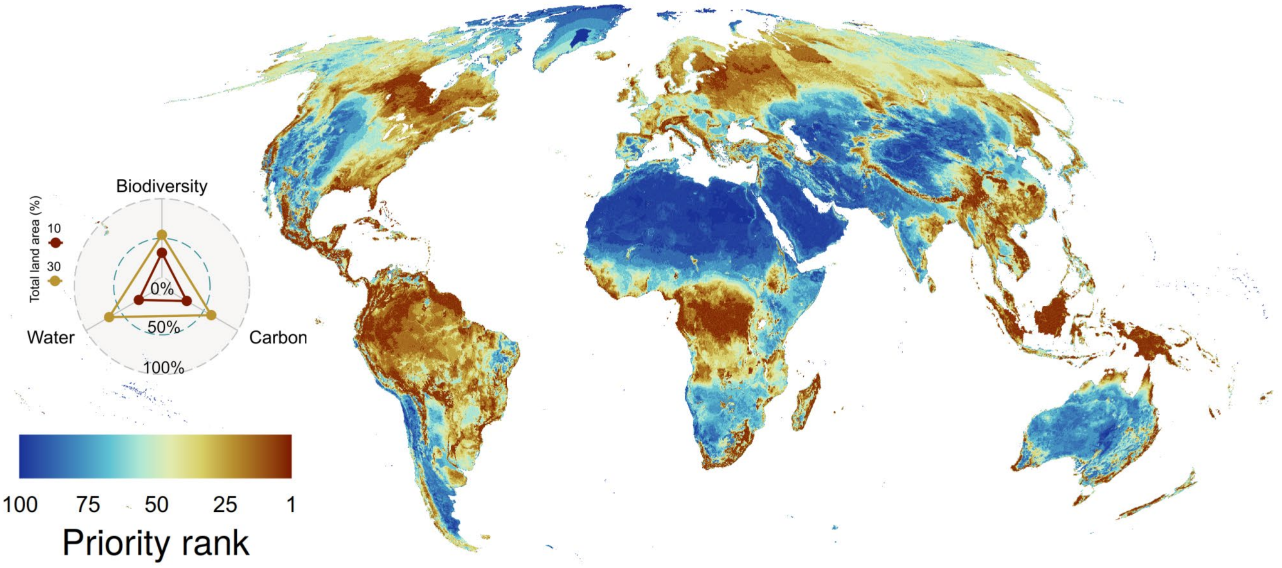
Another IIASA-led study also shows that integrated action would allow regional nitrogen boundaries to be reconciled with food security.[105] At the core of holistic solutions are a combination of consumption-side policies, international trade policies, and targeted sectoral measures accompanied by sustainable productivity increases, particularly in the least-developed countries. Here, too, however, careful design of the policies is needed to avoid unintended damage in specific regions and to specific groups of people.[55]

The recent development at IIASA of a new systems analysis research group focused on spatial ecology and conservation has catalyzed the production of new knowledge and tools for integrated assessment of biodiversity status and trends and associated policies.

IIASA-led research has shown how integrated spatial planning can conserve biodiversity and achieve other societal objectives at the same time. For instance, a study[49] found that integrating biodiversity and food production objectives in spatial planning for land use, as opposed to planning for each objective separately, could achieve similar biodiversity benefits at 25–40% of the opportunity cost for food production or 400–600% of the biodiversity benefit for similar opportunity costs. This shows that joint planning processes for rural development and biodiversity conservation are far more ecologically effective and socioeconomically feasible than separate strategies and planning processes for protection or restoration and rural development.

One recent study looked at targeting priority land areas for conservation, calculating the effects on species conservation, carbon storage, and clean water availability.[106] Optimizing all three objectives with equal weight, the study identified sites totaling 30% of land area that, if conserved, could help bring up to 81% of terrestrial vertebrate and plant species to the lowest extinction risk category, while retaining more than 60% of biomass carbon and preserving about 66% of clean water resources (see Figure 3.7).

Figure 3.7. **Global view of priority conservation areas when giving equal weight to three criteria—biodiversity, carbon storage, and water quality**



Note. 100% success in each criterion would correspond to no species under threat of extinction, no loss in carbon storage, and no loss in water quality. Adapted from Jung et al. (2021).[106]

These findings have inspired further research that has called for the adoption of ambitious and more holistic area-based conservation targets.[107,108] This has culminated in the adoption of the Kunming-Montreal Global Biodiversity Framework Target 1, which calls for all parties to adopt integrated, biodiversity-inclusive spatial planning across all marine, terrestrial, and freshwater systems.[109]

While some environmental problems, such as climate change, are truly global, and others, such as biodiversity, are being dealt with in global frameworks, the implementation of policies is national, and often even subnational. While global goals, including the goals of the Paris Agreement, are sometimes long-term, policy action is needed more quickly and must meet near-term targets, even though it is being implemented by decision-makers who are often elected for less than five years. Consistency across different spatial and temporal scales is another key requirement for effective policies. As illustrated in the example of climate change mitigation (Box 3.5), the IIASA land use modeling framework represents the land component of the global integrated assessment model MESSAGE/GLOBIOM,[42,110] and also of other integrated assessment models, including the International Energy Agency (Net zero pathways),[111] and the European Commission Joint Research Center[112] and the Centro Euro-Mediterraneo sui Cambiamenti Climatici (CMCC).[113] At the same time, the model is used by countries, including Brazil, Indonesia, the United States, and others for development of their national climate policies. The EC also uses the IIASA modeling framework,[114–116] and the results are closely scrutinized by EU member states. Using the same modeling framework from global to local scales makes national policies more consistent with global targets, while at the same time the feedback from local actors allows the global targets to become more realistic and corresponding strategies to be developed.

Box 3.5. Policy support across spatial scales—from global climate mitigation scenarios through EU level climate policies to local biodiversity hotspots*

Over the past two decades, IIASA research has been instrumental in providing the quantitative backbone for the EU Climate and Renewable Energy policies. IIASA's GLOBIOM and G4M models have played an important role in the analytical framework utilized by the EC to develop climate and energy policies, offering expertise and quantitative tools for the land use and biofuel–related assessments.

In 2011 the EC published its roadmap toward a low-carbon economy by 2050, which relied heavily on this assessment framework, and incorporated models such as PRIMES and POLES (energy), CAPRI (agriculture), and IIASA's GAINS (non-CO2s) and GLOBIOM/G4M (land use). Subsequently, the GLOBIOM/G4M models underpinned the development of the EU's long-term strategy toward 2050, entitled *A Clean Planet For All*,[115,117] as well as the legislative proposals for the 2030 Climate and Energy Framework.[118] The models also played a significant role in incorporating the Land Use, Land Use Change, and Forestry (LULUCF) sector into the 2030 Climate and Energy Framework.[119]

More recently, the GLOBIOM/G4M models have underpinned the development of the 2030 Climate Target Plan titled *Stepping Up Europe's 2030 Climate Ambition*,[116,120] as well as the Fit for 55 package.[121,122] GLOBIOM is also used to inform the biofuel policies of the international aviation (ICAO), the EU (EC) and USA (Environmental Protection Agency [EPA]) road transportation sector, helping to steer them toward cleaner feedstocks by assessing induced land use change effects and related emissions.[123–126]

The EU Green Deal has designed all policy packages for maximum integration and intersectoral coherence. Specifically, under the umbrella concept of "*Do no significant harm* [to the environment]" it is required that an economic activity should not be "significantly detrimental to the good condition and resilience of ecosystems or detrimental to the conservation status of habitats and species, including those of Union interest."[127] In this context, the IIASA-led BIOCLIMA project is assessing the feasibility and sufficiency of the Fit for 55 package and the EU Biodiversity Strategy, and supporting the EC in identifying implementation policies that maximize their synergistic effects on climate mitigation and biodiversity conservation while maintaining food and energy security. To aid this assessment the IIASA BNR program has developed methods to spatially simulate alternative implementation scenarios of the EU Nature Restoration Law and Protected Area targets, the two main pillars of the EU Biodiversity Strategy. This allows the simulation of specific restoration and conservation policies, including ecosystems and country-specific quantitative and qualitative targets and constraints.

A further development, which was needed to move from exploratory scenarios to policy assessment is the spatial and thematic downscaling of land cover, land use and management intensity to the resolution at which they affect biodiversity change. Finally, to model biodiversity responses to land use and climate change, IIASA researchers have developed new methods to unravel the intricate dynamics of plant functional diversity and adaptation in response to the environment,[128] and to integrate heterogeneous sources of biodiversity data using model-based integration[129] and improved biodiversity impacts (upcoming Hibiiscus model).

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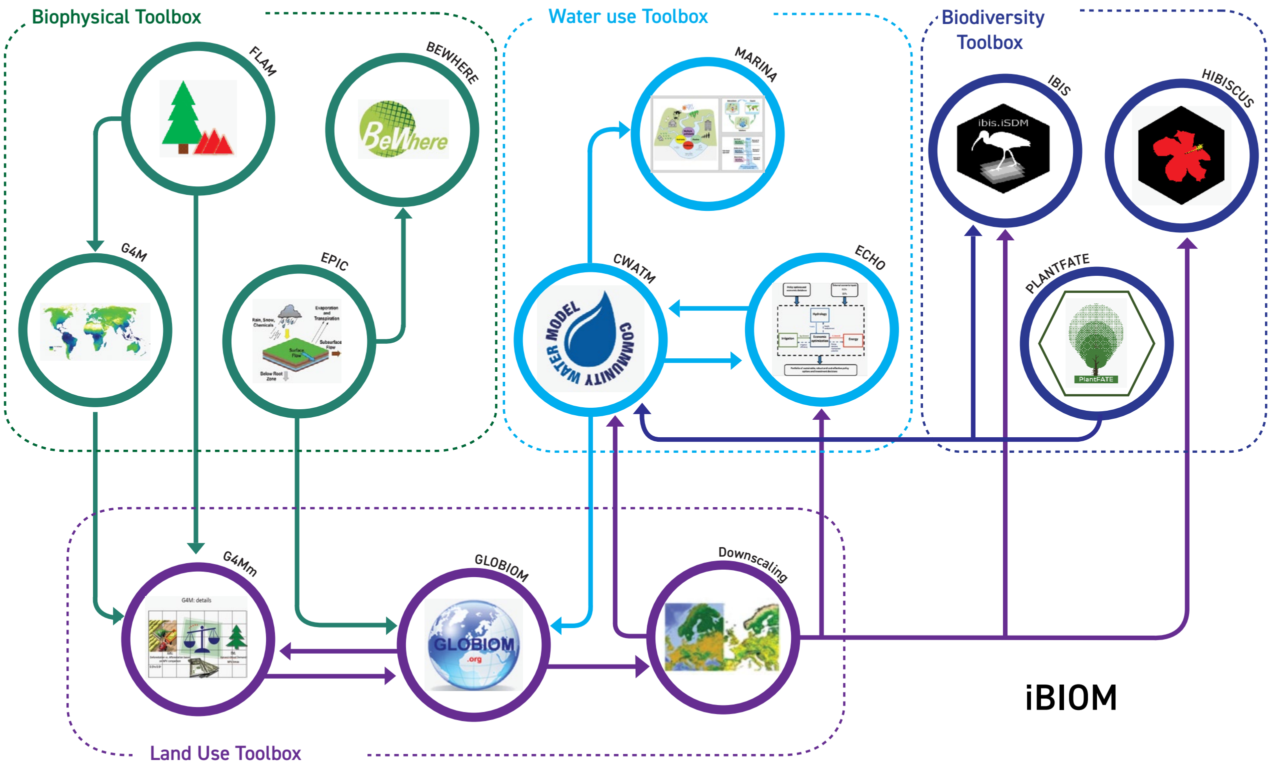
*Based on contributions from Stefan Frank and Piero Visconti

Integrated biosphere management modeling

The need to integrate across different sectors, sustainability dimensions, and spatial and temporal scales to address the new challenges has led to the development by IIASA researchers of the innovative Integrated Biosphere Management Modeling (iBIOM, https://github.com/iiasa/iBIOM). With its modular framework, iBIOM brings together established models and also models under development to form possibly the largest fully integrated ecosystems modeling suite in the world, now hosted by the IIASA Biodiversity and Natural Resources Program (Figure 3.8). iBIOM will be hosted on an open cloud-based computational infrastructure allowing researchers globally to use the models, to collaborate on developing existing modules, and to include additional modules as they see fit. iBIOM and its underlying infrastructure will thus contribute to boosting the modeling capacity of the global community to support decision-makers in development of sustainable biosphere futures.

Figure 3.8. **iBIOM modeling framework**

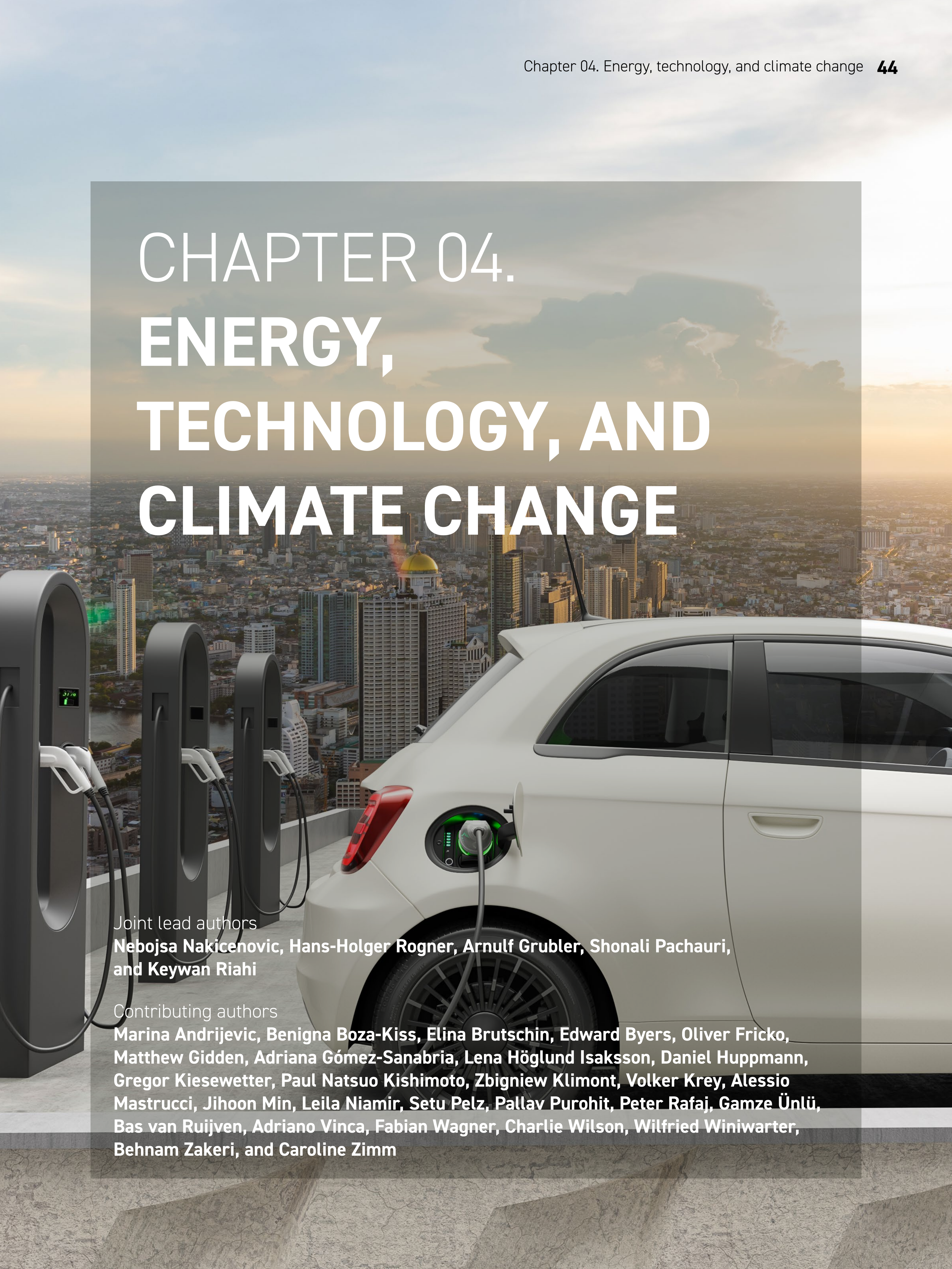


Note. Courtesy: Andrey Lessa Derci Augustynczik, IIASA.

Adequate policy assessment requires a comprehensive understanding of the ecological–economic systems that impact attainment of the SDGs and the consideration of the relevant drivers and levers to bring these systems to a safe and just operating space. The iBIOM offers an innovative approach to modeling that is firmly grounded in a nexus approach. It facilitates the integration of multiple sectors, such as land use, water, and biodiversity, in a cohesive manner, enabling a complete analysis of the impacts and interactions on and across sectors in response to biophysical drivers, policies, and adaptation options. iBIOM leverages the fully fledged suite of models developed by the BNR program at IIASA, which includes detailed biophysical models able to incorporate the effects of climate and management on agriculture (EPIC), biodiversity impact (IBIS, Hibiiscus) and dynamic vegetation changes (PlantFATE), forestry (G4M), wildfires (FLAM), and hydrology (cWatM), hydroeconomics (ECHO) and water pollution (MARINE). The biophysical information on productivity, water, and nitrogen impacts is explicitly considered in economic land use model (GLOBIOM) which is linked via a downscaling tool (DownscalR) to the other impact assessment models for forestry (G4Mm), biodiversity impact (IBIS, Hibiiscus)[130] and dynamic vegetation changes (PlantFATE).[131]

The iBIOM modeling framework will be hosted in a cyberinfrastructure dedicated to integrated models and data and efficient interfaces for the iBIOM modeling chains that are established. This will allow automated data assimilation procedures to be established, the streamlining of inputs and outputs, removal of redundancies in data harmonization efforts, and increases in the scalability of simulation efforts conducted by the iBIOM modeling framework. The cyberinfrastructure will be built around two main components, namely a scalable data store in the form of a distributed file system (DFS), and a high-throughput computing cluster (HTC). A platform control server at the top of this architecture will act as a controller for the DFS and HTC. Requests to this platform are made from a client API, which will dispatch simulation jobs and also include functionalities to explore the scenarios and data produced on a web interface.

With all these innovative and integrative modeling initiatives, IIASA aims to further strengthen its role in comprehensive systems analysis of the food security–land–vegetation–livestock–water–biodiversity nexus, including the social, economic, and governance challenges that will become even more relevant over the coming decades.



CHAPTER 04.

ENERGY, TECHNOLOGY, AND CLIMATE CHANGE

Joint lead authors
Nebojsa Nakicenovic, Hans-Holger Rogner, Arnulf Grubler, Shonali Pachauri, and Keywan Riahi

Contributing authors
Marina Andrijevic, Benigna Boza-Kiss, Elina Brutschin, Edward Byers, Oliver Fricko, Matthew Gidden, Adriana Gómez-Sanabria, Lena Höglund Isaksson, Daniel Huppmann, Gregor Kiesewetter, Paul Natsuo Kishimoto, Zbigniew Klimont, Volker Krey, Alessio Mastrucci, Jihoon Min, Leila Niamir, Setu Pelz, Pallav Purohit, Peter Rafaj, Gamze Ünlü, Bas van Ruijven, Adriano Vinca, Fabian Wagner, Charlie Wilson, Wilfried Winiwarter, Behnam Zakeri, and Caroline Zimm

4.1 Background and achievements over the past half century

The 1970s and 1980s

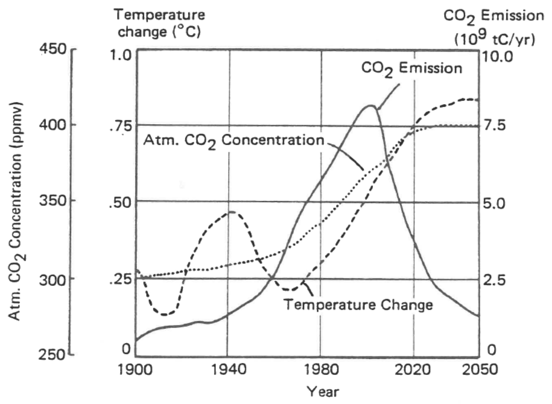
The IIASA Energy Program was established in 1973, half a century ago, by IIASA's founding Director, Howard Raiffa. Led by Wolf Häfele, it was one of the very first programs at the institute and proved to be a visionary step. The launch of the Energy Program coincided with the onset of the global energy crisis that emerged in 1973—with the subsequent oil price shocks and supply shortages heightening the urgent need to better understand the global energy system and its future development.

The key question was whether the world would run out of cheap and easily exploited fossil energy resources and how swiftly alternatives like nuclear energy and renewables, including wind and solar, could be either expanded or commercialized and put into use. Another important consideration was how energy end-use would evolve and whether quasi-zero emission electricity and hydrogen would become major energy carriers.

While there was no truly global energy study at that time, there were studies of the World Outside Communist Areas (W.O.C.A.), for example, the important 1973 Workshop on Alternative Energy Strategies. In 1972 the Club of Rome's well-known *Limits to Growth* study had indicated the world would run out of resources, including energy, should historical trends continue. The earliest work of the Energy Program at IIASA thus focused on improving understanding of the global energy system through the use of databases and models. Key to addressing this challenge, before digital databases even existed, was the gathering of evidence through data collection and vetting. There was also a focus on the development of global energy system models backed by such data, and this is where the unique role of IIASA came to the fore. Colleagues like Harry Maier and Tibor Vasko catalyzed the assessment of the global energy system to include the Soviet Union, other Warsaw Pact countries, and China. These pioneering efforts resulted in the first energy study to include Global South and North, East, and West.

IIASA developed an innovative, comprehensive, and evidence-based modeling framework to support the development of energy perspectives on how to proceed beyond the energy crisis. The institute undertook the first truly global energy assessment, with 11 world regions. This included model-based scenarios to 2030 and 2050, at that time 60 to 80 years into the future, and a path-breaking assessment of possible climatic consequences of the alternative energy system scenarios as illustrated for the median scenarios in the future. Rick Niehaus from the International Atomic Energy Agency (IAEA) and Jill Jäger (then Jill Williams) of IIASA worked with other colleagues on the long-term scenarios of future carbon dioxide emissions. Figure 4.1 illustrates one of the low scenarios from 1970s through to 2050 in the future. The scenarios developed showed it would have been possible to stabilize climate change gradually by adopting an alternative low-carbon development strategy. Today, however, because of the lack of actions taken during the past decades, the world will likely, over the coming decades, "overshoot" the long-term temperature target of the 2015 Paris Agreement "to avoid dangerous climate change by holding the increase in global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C"—even if net zero emissions are reached by the middle of this century.

Figure 4.1. **CO2 emissions, atmospheric CO2 concentration, and temperature change for a 30 TWyr/yr low-carbon development strategy that characterizes one of the scenarios presented in the *Energy in a Finite World***



Note. Source: Anderer, McDonald, and Nakicenovic (1981)[1] originally published in Niehaus & Williams (1979).[2] Copyright 1981 by IIASA.

Soon after its inception, the Energy Program formed a group under the leadership of Michel Grenon, that included, among others, Arnulf Grubler. The prevailing opinion of the day was that fossil energy resources would "last" about two decades. One of the landmark findings of these researchers' early work was that the "peaking" of fossil energy worldwide would not occur due to lack of resources (the then conventional view), but to environmental constraints and the planetary boundaries being breached due to, for instance climate change. This work, as it continued to develop, resulted in fundamentally new perspectives about energy futures, both at the time and in the decades to follow.[3] The environmental and climate-change boundary paradigm which was developed at IIASA has helped to fundamentally change global energy and climate science and policy debates ever since.

The long-term perspective of IIASA's energy scenario work, extending to 2030 and 2050, was motivated by two trends that were recognized as inherently long-term: first, the development needs of the Global South and second, the need to incorporate the results of the technology dynamics work at IIASA, particularly the work of Cesare Marchetti and Nebojsa Nakicenovic (who joined IIASA in August 1973), and later Arnulf Grubler. This empirical work indicated that substitution of primary energy takes decades and, at the global level, some 50 to 70 years. The work culminated in the development of the simple logistic model to describe these dynamics that, in turn, were used as market penetration constraints in the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE).[4] The modeling team at the beginning involved Malcolm Agnew, Hans-Holger Rogner, Leo Schrattenholzer, Alfred Voss, and starting in 1979 Sabine Messner and Manfred Strubegger.

The MESSAGE model evolved through many innovations and extensions (see Box 4.1). One of the first ones was to add a macro-economic module. This occurred in three stages—first a global economic model[5,6] as a soft-linked version; next, an integrated macro-economic module, led by Alan Manne;[7] the third, a detailed, bottom-up energy demand model, MEDEE, which soon joined the set to make a truly integrated energy systems model. Another important advance was the work on environmental dimensions of the energy system in the form of Water, Energy, Land, Manpower, and Materials (WELMM) analysis.[8] Early IIASA research laid the foundations for subsequent integrated assessment modeling work on the technological, macroeconomic, social, and behavioral determinants of energy demand, and first made explicit the possibly crucial role of decarbonization.

Cesare Marchetti at IIASA was the first to propose decarbonization of fossil energy sources through carbon capture and storage, primarily from natural gas which, having the highest hydrogen to carbon ratio, requires lower carbon storage requirements per unit energy.[9] His proposed strategies ranged from carbon separation at gas wells and storage of carbon in the field, to storing carbon in the deep ocean. Eventually, the main very low-carbon emissions energy sources would be renewables and nuclear, and potentially also fusion. Other ideas included siting nuclear power plants away from settlements or utilizing solar energy in North Africa and other sunny regions.[10]

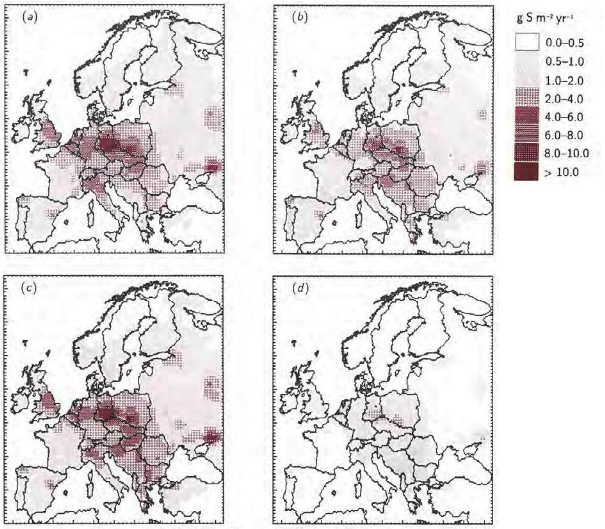
Brian Arthur was also at IIASA at that time working with Yuri Ermoliev on the question of technological lock-ins closely related to the phenomenon of increasing returns. William Nordhaus joined the Energy Program to work on the economic and technological challenges of the long-term energy system evolution. He soon joined others to work on greenhouse gas emissions from the energy system and their reduction through taxing carbon emissions.[11] The IIASA Workshop on Carbon Dioxide, Climate and Society held in 1978, was one of the earliest international assessments of the climate problem. It concluded that because knowledge of the climate system and the carbon cycle was so uncertain, a prudent energy policy would be to maintain flexibility.

All of these innovative research activities and others during the first decade of energy work at IIASA culminated in the two-volume flagship report *Energy in a Finite World* published in 1981.[1,12] Over seven years, hundreds of researchers contributed to the two monumental volumes on the central role of energy (and emissions) scenarios to 2030 of the evolving energy system. This was led by Wolf Häfele, with contributions from all members of the Energy Program; Wolf Häfele led the writing team, with support from Jeanne Anderer, Alan McDonald, and Nebojsa Nakicenovic in condensing the large volume of research into a single book and an executive summary of the study.

IIASA's energy and technology research focused during the 1980s on special issues like renewable energy futures, the role of nuclear technologies, and natural gas. Later, the restructured Energy Program undertook a study, led by Hans-Holger Rogner with Sabine Messner, Manfred Strubegger, and others, on natural gas futures in Europe.[13] Today, one would characterize this as an inclusive modeling and scenario-building approach that involved stakeholders from the public and private sector. Another study, drawing on unique international data, focused on the technological evolution of energy, mobility, production, and other systems.[14] This research, a direct continuation of the analyses that started in the Energy Program, was conducted by Arnulf Grubler, Nebojsa Nakicenovic, and other IIASA colleagues, as well as a large network of external collaborators like Jesse Ausubel. It provided the basis for pioneering work at IIASA in the technology domain in the 1990s and 2000s. David Victor joined the Energy Program to work on policy dimensions of climate change. He later led the International Negotiations Program and continued to work on technological change.[15]

During the 1980s, IIASA's research on acid deposition[16] that provided a comparison of the cost-effectiveness of alternative sulfur dioxide emissions reduction options, informed the Geneva Convention on Long Range Transboundary Air Pollution (LRTAP, see Figure 4.2).[17] The Regional Acidification Information and Simulation (RAINS) model was adopted by the member countries of the convention as the main technical support for the negotiations of the treaty. This is the first time that all parties to a major international treaty agreed to accept a single scientific model. This work was led by Leen Hordijk, who later also served as IIASA director in the 2000s.[18] Markus Amann joined the team working on acid rain in 1986, and later led the air pollution work at IIASA for almost three decades between 1991–2020.

Figure 4.2. **RAINS maps of calculated sulfur deposition in Europe for the following scenarios and years: (a) 1980; (b) Current Reduction Plans, 2000; (c) No Controls, 2000; and (d) Best Available Technology, 2000**



Note. Source: Alcamo, Shaw, and Hordijk (1990).[16] Copyright 1990 by IIASA and Kluwer Academic Publishers.

Box 4.1. Development of the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE)

By Oliver Fricko, Hans-Holger Rogner, and Behnam Zakeri

MESSAGE is a dynamic process-based integrated assessment model. At its core is a detailed representation of technical-engineering, socioeconomic, and biophysical processes in energy and land use systems. MESSAGE aims to satisfy a given demand profile, at least cost, subject to operational, infrastructure, market penetration and policy constraints.

MESSAGE is an outgrowth of the Häfele–Manne model, which had electricity supply at its core and demand as an exogenous input. Recognizing the narrow electricity supply focus of the model, Wolf Häfele initiated the model's expansion into a full-scale least-cost energy system optimization model which soon after became known as MESSAGE.[4,19,20] The early versions of MESSAGE were hybrid constructs with various soft-linked sub-models covering different aspects and drivers of the energy system. The Macroeconomic model (MACRO)[6,21] evaluated the market clearing equilibrium conditions of the aggregate macroeconomic production factors (energy, capital, and labor). Socioeconomic development and the resulting impact on the demand for energy services was the contribution of the Model for Long-Term Energy Demand Evaluation (MEDEE).[22] The Economic Impact Model (IMPACT)[23] calculated the required direct and indirect costs of different energy demand and supply strategies for assessing the financial viability, while a WELMM[8] analysis accounted for water, energy, land, materials, and manpower requirements of different energy strategies and scenarios. WELMM was a forerunner of today's NEXUS models.

MESSAGE model development has been a rolling process driven by (a) new challenges (e.g., responding to climate change and the role of global energy system transformation), innovation and technology learning, and (b) new and more powerful IT hardware.

By the mid-1990s, MESSAGE had mutated from a predominantly energy supply-side optimization model to a comprehensive energy system model.[24] Pioneering work on endogenizing technological learning into an energy system model was accomplished by Sabine Messner.[25] MACRO, meanwhile hard linked to MESSAGE, accounted for cost effects on energy demand.[7] A stochastic version enabled the analysis of alternative approaches to risk modeling and the impact of hedging on transition pathways.[26,27]

Rao et al.[28] analyzed the role of multiple non-CO2 greenhouse gases through a detailed accounting of pollutants in accordance with the Shared Socioeconomic Pathways (SSPs)[29,30] relying on data provided by GAINS.[31] Sullivan et al.[32] and Johnson et al.[33] developed methodologies to specifically represent the challenges presented by variable renewable electricity sources on reliable 24/7 electricity supply. With the development of an endogenous integration[34] with the land use model GLOBIOM[35] and the forestry model G4M,[36] MESSAGE evolved into a complex IAM framework. Finally, MAGICC,[37] a global carbon-cycle and climate model, provides estimates of the climate implications in terms of atmospheric concentrations, radiative forcing, and global-mean temperature increase.

MESSAGE analyses have routinely informed and furthered the science–policy interface by contributing to several highly visible projects: for the World Energy Council (WEC) global energy scenarios up to 2050;[38] for the IPCC Special Report on Emissions Scenarios (SRES) a central emissions scenario;[39] for the *Global Energy Assessment* (GEA) scenarios;[40] as one of the marker scenarios for the Representative Concentration Pathways (RCPs);[41] as well as for the Shared Socioeconomic Pathways (SSPs);[34] and for two studies for the United Nations Economic Commission for Europe (UNECE) *Pathways to Sustainable Energy*[42] and Carbon Neutrality in the UNECE Region.[43] MESSAGE scenarios have routinely informed the Intergovernmental Panel on Climate Change (IPCC).[44]

With the modernization of the underlying code and data processing infrastructure,[45] the MESSAGEix modeling framework was born as an open-source version to serve the user community in a transparent and reproducible way. With this, MESSAGEix not only benefited from a technical modernization, but could also integrate modular extensions with more ease, thereby extending the breadth of the model coverage from a substance perspective. MESSAGEix-Nexus,[46] MESSAGEix-Access,[47] MESSAGEix-Materials,[48] MESSAGEix-Buildings,[49] and MESSAGEix-Transport,[50] are all extensions of the core model (MESSAGEix-GLOBIOM),[51] and provide deeper understanding of key sectors. With the recent release of the baseline-scenario data,[52] MESSAGEix-GLOBIOM is now available for use by the wider scientific modeling community.

The 1990s

During the 1990s focus changed toward more integrated assessments, endogenization of technology dynamics, and contribution to major international scientific and policy efforts such as the Intergovernmental Panel on Climate Change (IPCC). IIASA helped establish the foundations of climate change assessment through research and strong involvement in the two meetings in Villach, Austria, that provided the scientific basis for establishment of the IPCC by the World Meteorological Organization and the United Nations Environment Programme (UNEP) in 1988 (see also Section 1.3 in Chapter 1). After the IPCC had been established, IIASA scientists became important contributors to the assessments, starting with the Energy and Industry Subgroup (EIS) of the First IPCC Assessment Report. Since then, IIASA scientists have continued to be lead authors on all IPCC assessments and most of the special reports, with 11 coordinating and lead authors on the most recent IPCC Sixth Assessment Report.

One early and influential collaboration in the energy area was the joint project with the World Energy Council (WEC) which started in 1992, with IIASA contributing analytical capability. The results were presented at two WEC Congresses and published as *Global Energy Perspectives* in 1995 and 1998.[53,54] Central to this research were global energy scenarios that included future transformational change, and back then controversially presented two pathways that stabilized climate change at about 2°C above preindustrial levels.

During the early 1990s, it became clear that different research communities working on climate change needed to collaborate in an integrated scenario approach. Elementary scenarios had already been produced for the IPCC in the First Assessment Report. These were reviewed by a team that included IIASA researchers. A team was subsequently set up to develop new reference scenarios to achieve greater integration into the IPCC. The resulting reference scenarios from the Special Report on Emission Scenarios (SRES)[39] became a basic reference across the world, not just for climate model runs, but also for a wide range of analyses. IIASA research in this area also grew with new colleagues, notably Keywan Riahi, who now leads energy and climate research at IIASA, and Alex Roehrl, currently at the United Nations Department of Economic and Social Affairs (UN DESA), working on the 2030 Agenda.

Under the leadership of Markus Amann, IIASA's work on cost-effectiveness of air pollution mitigation (with the RAINS model) supported negotiations of the 1999 Gothenburg Protocol to abate Acidification, Eutrophication and Ground-level Ozone; the multi-pollutant treaty, within the Convention on Long-Range Transboundary

Air Pollution, set national emission ceilings for several air pollutants. Successful application of the RAINS multi-pollutant and multi-effect modeling framework in Europe, subsequently enabled development of the RAINS-ASIA model that addressed growing environmental pressures, specifically due to emissions and deposition of acidifying substances, in Asia. This was a collaborative effort of several institutions in Asia, Europe, and North America with support and participation of ministries and agencies in Asia, Europe, and the Asian Development Bank.[55]

The 2000s and 2010s

In 2006 the scientific community called for new scenarios endorsed by the IPCC to replace the SRES scenarios. IIASA played an instrumental role in the design of the new generation of scenarios, the so-called Representative Concentration Pathways (RCPs) and the Shared Socioeconomic Pathways (SSPs).[56] The new framework established a set of narratives with basic quantitative elements, such as population and GDP. The resulting scenario development process across the climate change community was coordinated by Keywan Riahi and Detlef van Vuuren, establishing the basis for an integrated approach for mitigation, adaptation, and impacts analysis (see also Section 1.3 in Chapter 1).[30,57]

These advances in understanding complex interactions of human and Earth systems were made possible at IIASA through the integration of its modeling approaches. This extended across research groups, as evidenced by the close collaboration between IIASA energy researchers and those responsible for the air pollution systems models, RAINS and later GAINS (see Box 4.2), which established IIASA as the leading institution for integrated energy and air pollution analysis.[58] While integration of models across research groups with different research agendas was challenging, it gave IIASA a unique position as a one-stop shop for consistent modeling of global energy, land use, and water systems: all informed by shared demographic, economic, and technological drivers. Thomas Schelling, a frequent visitor to IIASA at the time, catalyzed and intellectually supported the difficult way toward an integrated modeling approach at IIASA, the so-called Greenhouse Gas Initiative (GGI). The GGI was an inter-project collaborative research effort to develop the next generation integrated modeling and decision support framework for climate change, its anthropogenic driving forces and possible response strategies. The outcomes of this initiative put IIASA in a leading position to provide evidence-based modeling advice on a range of human and Earth systems challenges, including important nexus issues such as energy, land, and water. Results were published as a special issue of the journal *Technological Forecasting and Social Change* in 2007.[59]

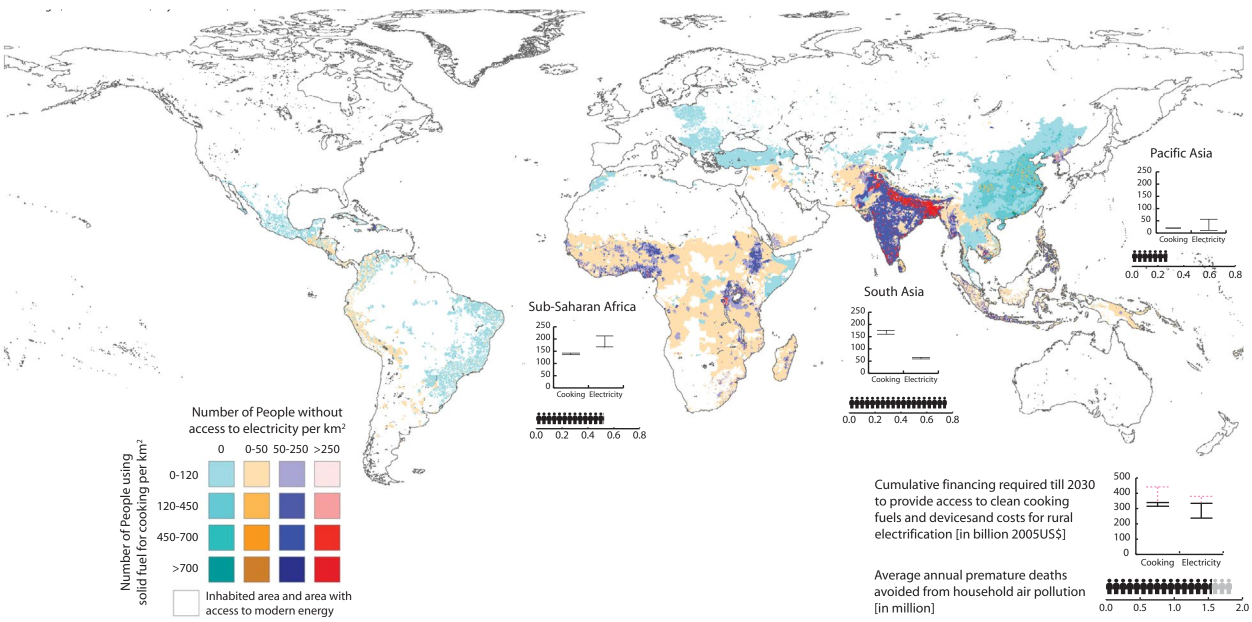
Work continued at IIASA in the new Energy Program which was later divided into the Energy Systems Program and the Transitions to New Technology Program. The new millennium regrettably began with a setback—the failure to include energy in the Millennium Development Goals (MDGs), which established the international sustainable development priorities for 2000–2015. As the omission of energy held true even for the early IPCC work, it was decided to include an energy primer in the IPCC Second Assessment Report,[39] which was later updated for the *Global Energy Assessment* (GEA).[60]

In this connection, the UN Secretary-General, Ban Ki-moon, established a high-level Advisory Group on Energy and Climate Change (AGECC), to which Nebojsa Nakicenovic was appointed. Its report, *Energy for a Sustainable Future*,[61] published on 28 April 2010, provided recommendations on energy issues in the context of climate change and sustainable development.

The recognition that energy was not an end in itself but essential for the services and multiple wellbeing benefits it can provide, as well as the implications for sustainability that energy systems entail, led to the organization of the *Global Energy Assessment* (GEA) at IIASA by a large and eminent scientific team, and with backing from Bert Bolin and Jose Goldemberg.[62] The GEA emerged as an authoritative and comprehensive, evidence-based assessment, much like those of the IPCC, to put energy on the agenda for the Rio+20 Summit. It was written by 200 authors and 300 peer-reviewers and supported by several governments including Austria, Brazil, Sweden, and the United States. The results, published in 2012 by Cambridge

University Press,[62] constituted a comprehensive assessment of energy challenges and the way forward informed by integrated scenarios,[40] ranging from energy resources and technologies, all the way to energy end-use; and for the first time some of the biggest challenges—the lack of access to clean and affordable electricity and cooking fuels predominantly in developing countries was also presented (see Figure 4.3).[63]

Figure 4.3. **Global distribution of population without access to modern energy with estimates of cumulative costs for achieving universal access by 2030 and deaths avoided in 2030**



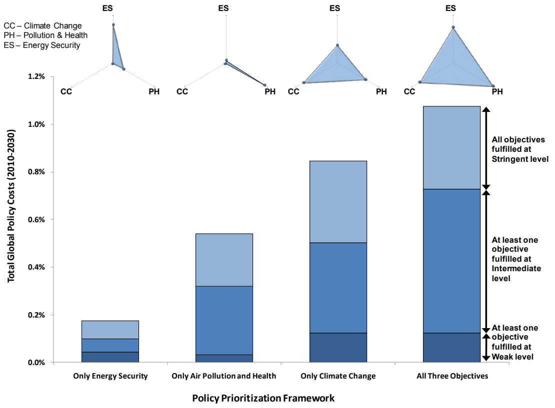
Note. Source: Pachauri et al. (2013).[64] Reprinted under the terms of the Creative Commons Attribution 3.0 International License.

The GEA scenarios were influential in highlighting the critical importance of energy demand options and diverse technology portfolios in addressing the multitude of development challenges while remaining within planetary boundaries, particularly with respect to climate change. Pioneering work at IIASA specifically illustrated the power of integrating objectives and sectors to address the energy challenges effectively, minimizing trade-offs while maximizing synergies (see Figure 4.4).

A tangible result of the AGECC, the GEA, as well as analyses from the World Bank and the International Energy Agency (IEA), was the inclusion of energy in the Sustainable Development Goals (SDGs), launched in 2015 as part of the 2030 Agenda, a plan of action for people, planet, and prosperity. Energy became SDG 7. Important work at IIASA, at this time, also informed the temperature targets of the 2015 Paris Agreement, in particular research on emission pathways in line with 1.5°C and 2°C of global warming.[65,66]

Several pioneering contributions were made in the domain of technology studies too during this period. Among others, came the development of a technology innovation systems approach, empirical case studies on the successes and failures of technology innovation policies,[68] and modeling the phenomenon of increasing returns and technology spillover effects,[25] including massive simulations with a CRAY supercomputer. Pioneering work was also carried out to identify the sources of uncertainty in learning phenomena that lead to increasing returns, including cases of "negative learning";[69] the innovation, learning, and implementation advantages of (small unit-scale, distributed) "granular" technology options were also demonstrated.[70] Modeling work also illustrated the importance of up-front investments in a portfolio of options in order to hedge against long-term innovation uncertainties.[71]

Figure 4.4. **Costs of achieving societal objectives for energy sustainability under different policy prioritization frameworks**

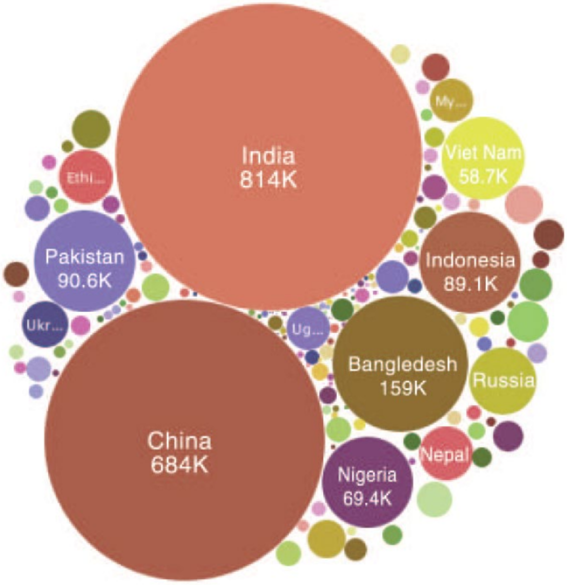


Note. Source: McCollum, Krey, and Riahi (2011).[67]

Collaborative research between IIASA and NASA's Goddard Institute for Space Studies was also the basis of the Climate and Clean Air Coalition (CCAC), an initiative to reduce short-lived climate pollutants, announced in 2012 by then U.S. Secretary of State, Hillary Rodham Clinton. Work by the two institutes pinpointed 14 of several hundred GAINS model options for improving air quality (Figure 4.5) that also had the greatest climate benefits.[72] Similar assessments, addressing simultaneous mitigation of air pollutants and short-lived climate forcers,[73] have been performed with the GAINS model for Latin America,[74] Asia,[75] and the ASEAN region.[76]

In addition to informing the SDG 7, IIASA contributed to understanding the complex relationships among the 17 SDGs and their 169 targets, launching The World in 2050 Initiative (TWI2050) in 2015 with the Sustainable Development Solutions Network, the Stockholm Resilience Centre (SRC), and others. The aim of TWI2050 was to provide research in support of successful implementation of the 2030 Agenda, by providing fact-based knowledge to support the SDGs policy process and implementation, thereby maximizing synergies among the goals, minimizing any trade-offs, and simplifying overall complexity. The results, articulated in numerous scientific assessments,[77,78] pointed to six transformations that capture much of the global, regional, and local dynamics and encompass major drivers of future changes: i) Human capacity and demography; ii) Consumption and production; iii) Decarbonization and energy; iv) Food, biosphere and water; v) Smart cities; and vi) Digital revolution. The transformations have also been considered by the United Nations High-level Political Forum on Sustainable Development (HLPF) and the International Science Council, of which Nebojsa Nakicenovic is a Fellow, in their 2023 HLPF Fellows statement.[79]

Figure 4.5. **Annually avoided premature deaths (values for population over age 30) in 2030 due to measures reducing emissions of CH4 and BC versus the reference scenario**



Note. Source: Shindell et al. (2012).[72] Reprinted with permission from AAAS.

Box 4.2. Supporting policy to efficiently address air quality and climate change using the GAINS model

By Zbigniew Klimont, Gregor Kiesewetter, Lena Höglund-Isaksson, Peter Rafaj, and Fabian Wagner

The IIASA Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model provides a framework for assessing strategies that reduce emissions of multiple air pollutants and greenhouse gases at least cost, and minimize their negative effects on human health, ecosystems and climate change.[31,80]

By the 1970s, acid rain caused by pollution from energy generation, industrial sources, motor vehicles, and agriculture, was triggering severe damage to the European environment. Prevailing winds transported pollution across national borders so that low-polluting countries experienced more than their fair share of pollution "fall-out." To combat transboundary pollution, an international treaty, the Convention on Long-range Transboundary Air Pollution, was negotiated in 1979. This framework convention, proposed by the UN Economic Council for Europe,[17] is one of the oldest and most successful international treaties protecting the environment.

When negotiating a new treaty in 1979, policymakers and scientists understood that making uniform cuts in emissions across countries would not be efficient or effective. Getting states to negotiate a consensus on cutting emissions would also require tactical diplomacy and scientific proof. IIASA's interactive Regional Acidification Information and Simulation (RAINS) model provided both and it helped in analyzing the costs and impacts of various measures to ensure fair negotiations.

In 2006, IIASA launched the on-line GAINS (https://gains.iiasa.ac.at/models/) model application (as an extension to the RAINS model) providing a framework for assessing strategies that reduce emissions of multiple air pollutants and greenhouse gases at least cost and minimize their negative effects on human health, ecosystems, and climate change.

Since 1995, RAINS/GAINS have provided quantitative scientific analyses for the key policy initiatives of the European Commission in the areas of air pollution and climate change, including the National Emission Reduction Commitments Directive (2001/81/EC; 2016/2284/EU), the 2014 European Commission proposal on climate targets, and recently the European Green Deal where the GAINS model was used to estimate necessary reductions of non-CO2 GHGs.[81–84]

The capacity to assess co-benefits of climate and air quality policies resulted in the application of the GAINS model to design global and regional strategies to improve air quality and simultaneously provide the greatest climate benefits.[72]

Most recent GAINS model development focuses on finer scale applications, resulting in adoption of the model by the Chinese government to assess air quality management plans for the Jing-Jin-Ji region,[85] and applications for Hanoi, Vietnam,[86] Johannesburg, South Africa, and the Indo-Gangetic Plain (India).[87]

Overall, IIASA and the GAINS model have been instrumental in providing scientific evidence and analysis for effective policymaking, helping combat air pollution and its adverse effects on human health, ecosystems, and climate change. Their contributions have shaped international agreements, European and, recently, Asian initiatives, driving significant progress in improving air quality and environmental protection.

4.2 Current challenges and the way forward

Many of the challenges identified by IIASA's first Energy Program are still relevant today. Some have become more urgent, as human activities push the Earth system past potentially disastrous tipping points.[88] IIASA's Energy, Climate, and Environment (ECE) Program, created in 2021, aims to find feasible systems transformations to address challenges at the intersection of energy, environment, and climate change that will put the world on track to meeting the goals of the 2030 Agenda for Sustainable Development and the 2015 Paris Agreement. The new ECE program also continues to serve as a data hub for the global modeling community (see Box 4.3). Key research undertaken over recent years and areas that will continue to remain the focus of its future activities are highlighted below.

Box 4.3. Open access/data, models, and tools

By Daniel Huppmann and Volker Krey

Over the past years, a paradigm shift toward open science has taken place in the research community: scientific colleagues, funders, and society at large now generally expect that not just the results of scientific research, but also the data, models and tools used to derive any insights, should be made openly available. Prominent examples of this trend are the *Plan-S* to require open-access publications from publicly funded research projects or the condition of the European Union research and innovation program Horizon Europe, that any research data and models are released under an open-source license.

IIASA has long supported the transition toward Open Science for which IIASA's role as a community data hub for transformation pathways is a prime example. IIASA co-led the development of reporting standards for within the integrated assessment modeling community.[89] For more than a decade, IIASA has hosted scenario datasets on behalf of the Integrated Assessment Modeling Consortium (IAMC), the Intergovernmental Panel on Climate Change (IPCC),[90] and many research projects and national assessments. An overview of high-profile initiatives and projects using the IIASA infrastructure is shown at https://data.ece.iiasa.ac.at.

At the institutional level, the Open Science Strategy and the introduction of dedicated "FAIR Data Stewards" across all research programs illustrate this transition. This fosters transparency and intelligibility of scientific knowledge.

The Energy, Climate and Environment (ECE) Program has been leading the development of open-source models and tools at IIASA. The MESSAGEix Integrated-Assessment Modeling Framework was reimplemented and released under an open-source license (Huppmann et al., 2019);[45] the accompanying input dataset for replicating the MESSAGEix baseline scenario used in a recent application is available on Zenodo;[52] workflows to generate new model variants are published in code repositories (e.g., MESSAGEix-Nexus);[46] and numerous other tools and packages are developed by researchers and software developers in the ECE program, for example the Python package pyam for scenario analysis and data visualization.[91]

Just, inclusive, and equitable energy system transitions

While global energy supply and use have expanded tremendously over the last five decades, energy inequalities persist. IIASA and other research has shown how global challenges such as the COVID-19 pandemic have stalled advances in expanding access to modern energy services to the unserved and underserved, or have even led to deterioration.[92,93] Even in 2021, 675 million people lived without electricity and 2.3 billion people were reliant on harmful cooking fuels. At the same time, climate change impacts are accelerating, disproportionately affecting disadvantaged and more vulnerable communities and people.[94]

IIASA, as a founding member of the Global Commons Alliance, which emerged as a follow up to the work on *Global Commons in the Anthropocene*,[95] has contributed to the design of global and regional "just transition" pathways. Such pathways aim to not only safeguard stable and resilient conditions on Earth but also enable a prosperous and equitable future for its people.[96] IIASA research has explored how access to energy services and decent living standards affect GHG emissions, how climate mitigation policies impact different segments of the population, and how mitigation policies can be designed to avoid potential trade-offs with energy access and human wellbeing.[97,98,64,99,100]

Using a systems analysis approach, recent research has been exploring how multidimensional deprivation, access to energy services, and changes in the Earth system intersect (e.g., via heat stress, air pollution, water availability) across time and space, providing highly granular and spatially explicit data to support policy design and targeting.[101,102] At the same time, IIASA researchers are broadening the notion of justice reflected in climate policy research to go beyond effort sharing and emissions allocations, and are also working with stakeholders to learn about their perceptions on justice.[103]

Water, energy, land, and climate nexus

For almost a decade, IIASA researchers have used systems approaches to probe the nexus areas between water, energy, land, and climate, primarily at the global scale but increasingly at also national and river basin scales. Recent work has focused on identifying vulnerability hotspots under climate and socioeconomic development scenarios.[104] Integrated assessment models have also been extended to identify infrastructure requirements in the energy, water, and land system to comply with future demands, mitigation policy targets, and climate impacts at global scales[46,105] and at regional scales.[106] Changes in crop yields and water requirements, water availability and seasonality, and unpredictable disruptive events, could weaken the resilience of the current system and will require adaptation measures.[107] To address modeling challenges, future research must focus on the development of climate indicators across a broad range of impact dimensions. These must be assessed under different socioeconomic scenarios to better understand climate impacts, vulnerability, and the potential for risk reduction. IIASA is hosting the new Climate Solutions Explorer (www.climate-solutions-explorer.eu), a comprehensive resource that visualizes and presents vital data, including global coverage of climate impacts and national dashboards of mitigation options and climate impacts at the country level. The climate impacts work supports MESSAGEix model development to further incorporate and emulate climate impacts in the global and national models and thereby better account for the benefits of mitigation and risks of climate change. This will better characterize—at the country level—the potentials of, and limits to, climate change adaptation, and contribute to understanding the trade-offs and synergies with climate mitigation.[108]

Reaching Net Zero and potential needs for Carbon Dioxide Removal (CDR)

There are multiple strategies available to transition global energy and economy systems from the current level of ~55 Gt CO2-eq emissions to net zero before the end of the century. How quickly this milestone is achieved will determine the ultimate temperature and climate change impacts that humans will experience.[109] To investigate the trade-offs, co-benefits, and feasibility of these transitions, researchers at IIASA have used and extended MESSAGEix-GLOBIOM to a state-of-art global Integrated Assessment Model (see Box 4.1). In particular, new modules and scenarios have been developed to study the intersection of multiple competing requirements and strategies, including decent living, while recognizing the practical limitations of current institutional capacity for implementing ambitious climate policy in the Global North and Global South.

Recognizing the extremely limited and rapidly closing window to limit warming to 1.5°C, novel methods of removing carbon dioxide from the atmosphere (so-called Carbon Dioxide Removal [CDR]) are increasingly being considered as part of new mitigation pathways. As part of the GeoEngineering and NegatIve Emissions pathways in Europe (GENIE, https://iiasa.ac.at/projects/genie) project, IIASA scientists are extending the MESSAGEix-GLOBIOM model to include Direct Air Capture (DAC) and exploring new land use transition pathways to enhance the uptake of carbon in soils and on agricultural fields. While these novel approaches can support achievement of global net zero emissions in the long term, the latest findings of this research show that they would likely play a limited role in pathways that hold warming to the 1.5°C limit of the Paris Agreement.[43]

Non-CO2 greenhouse gas mitigation

It is becoming increasingly evident that limiting the emissions of non-CO2 greenhouse gases (GHGs), like methane (CH4), nitrous oxide (N2O), and fluorinated gases (HFCs, PFCs, SF6), will be key to keeping the world within global temperature targets, in particular, in the next few decades. Despite this, mitigation of non-CO2 GHGs has received relatively little attention compared to carbon dioxide (CO2), which remains the main culprit for long-term global warming. The GAINS model framework operated by IIASA's Pollution Management (PM) group has a well-established capacity to assess current and future anthropogenic non-CO2 GHG emissions across all source sectors, including future mitigation potentials and costs.[110–113] This capacity has been widely used for providing analytical input to policy impact assessments at country, regional, and global scales. Recent work includes contributions to the *European Green Deal* and Fit for 55 proposals,[114] the *Global Methane Assessment* reports by UNEP[115,116] used to underpin the Global Methane Pledge adopted at COP26 in Glasgow 2021, the Global Carbon Project's assessments of global nitrous oxide and methane emissions,[117,118] and the *Cooling Emissions* report by UNEP and IEA[119] used to evaluate the 2016 Kigali Amendment to the Montreal Protocol. An important conclusion is that addressing non-CO2 GHGs is effective in limiting short-term warming, relatively inexpensively, and comes with substantial co-benefits, for example, reduced human health impacts and crop yield losses from ozone exposure when methane (CH4) emissions are reduced. Strong links between policies addressing short-lived climate forcers and air quality create opportunities to support development of effective strategies to address other goals to reduce impacts on human health and ecosystems, including achievement of the WHO air quality guidelines, which remains a global challenge.[120,121]

Managing pollution across different media

Coming from a strong tradition of air pollution impact assessments (see Section 4.1 and Box 4.2), IIASA is extending its pollution analyses to other media such as water and soils. Recent research has centered on accounting for pollution impacts on aquatic environments, for example, quantifications of current and future (2040) amounts of municipal solid waste disposed of in the world's rivers, lakes, and coastal areas.[122] An ongoing study is investigating and evaluating critical impact levels on marine life from Polycyclic Aromatic Hydrocarbons (PAHs) and metals, specifically in the context of interaction with air pollution (via deposition from the atmosphere) and with air pollution abatement (considering impacts of scrubbers to clean shipping emissions). At the same time, eutrophication impacts on marine environments are being considered using the concept of Critical Atmospheric Inputs for nitrogen compounds. The environmental fate of nitrogen compounds has been used as a case study to assess multiple interactions, co-benefits, and trade-offs of management options.

Energy demand

Traditionally, energy systems are described as supply chains for satisfying energy demand. So far research on energy systems transitions has largely focused on energy generation and supply technology diversification and innovation. This legacy approach has two key limitations. First, it ignores that energy is primarily a means to satisfy the provision of necessary services such as illumination, cooking, heating, cooling, and mobility. Second, the energy and exergy losses from extraction and production for ensuring these services are large. Up to 94% exergy is expended during the transformation of energy sources to service levels, and savings in energy demand, namely at the service or final energy levels, are critically important for effective and rapid energy transitions.[40]

IIASA was a pioneer in understanding the trends and dynamics of technological change and innovation as they affect energy demand.[123] The seminal Low Energy Demand (LED) scenario study illustrates how historical trajectories of ever-rising energy demand leading to cumulative resource and environmental impacts can be reversed through the combination of demand-side technological, structural, and socio-behavioral innovations (see Figure 4.6).[124]

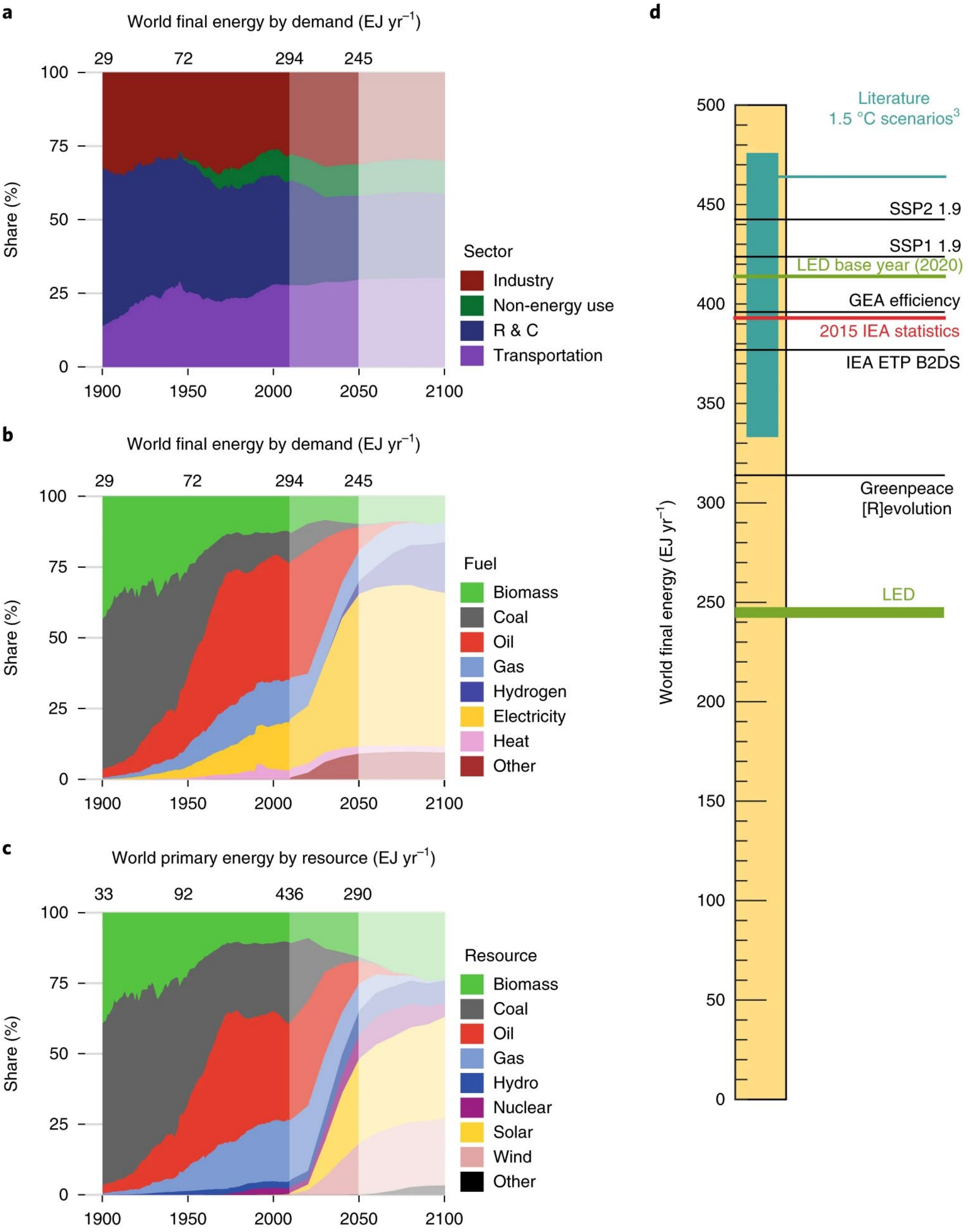
Transformations in mobility services, heating and cooling, and the devices and appliances necessary for a decent living standard have the potential to meet the UN SDGs, while also remaining within the 1.5°C target set by the 2015 Paris Agreement, and without relying on negative emissions technologies. A demand-side approach can thus better inform detailed, human-centric solutions, while also providing a complementary macro-level understanding of resource needs for a decent level of wellbeing.[98] IIASA is currently coordinating the Energy Demand changes Induced by Technological and Social innovations (EDITS, https://iiasa.ac.at/projects/edits) initiative to strengthen the demand-side research community, and further the knowledge on transdisciplinary topics of the demand-side, transferring methodological information, and exploring modeling innovations across demand-side models. This work brings together ongoing research exploring the development–climate nexus[97,125] and new modes of service provision.[126] It also highlights the potential role of digitalization (see Figure 4.7) for more efficient service provisioning that involves greater sharing and substitution of physical activities.[127]

Lifestyles and behavior change

Over the past decade, focus on behavior and lifestyle change has been reemphasized as an essential and integral element of analysis, policy, and action. An important conceptual advance has been to bridge the previously common distinction between technological and behavioral change, recognizing that people's preferences, choices, and actions as citizens, consumers, households, and communities are powerful agents of change in both the social and material contexts.[128] New analysis has shown how international and national climate commitments are more achievable if policies and interventions are designed to account for behavioral, social, and institutional factors alongside the more narrow set of technical and economic factors on which conventional modeling and analysis has been based.[125,129] This includes the enduring effects of the biggest behavioral disruption of recent times: pandemic-driven lockdowns.[130]

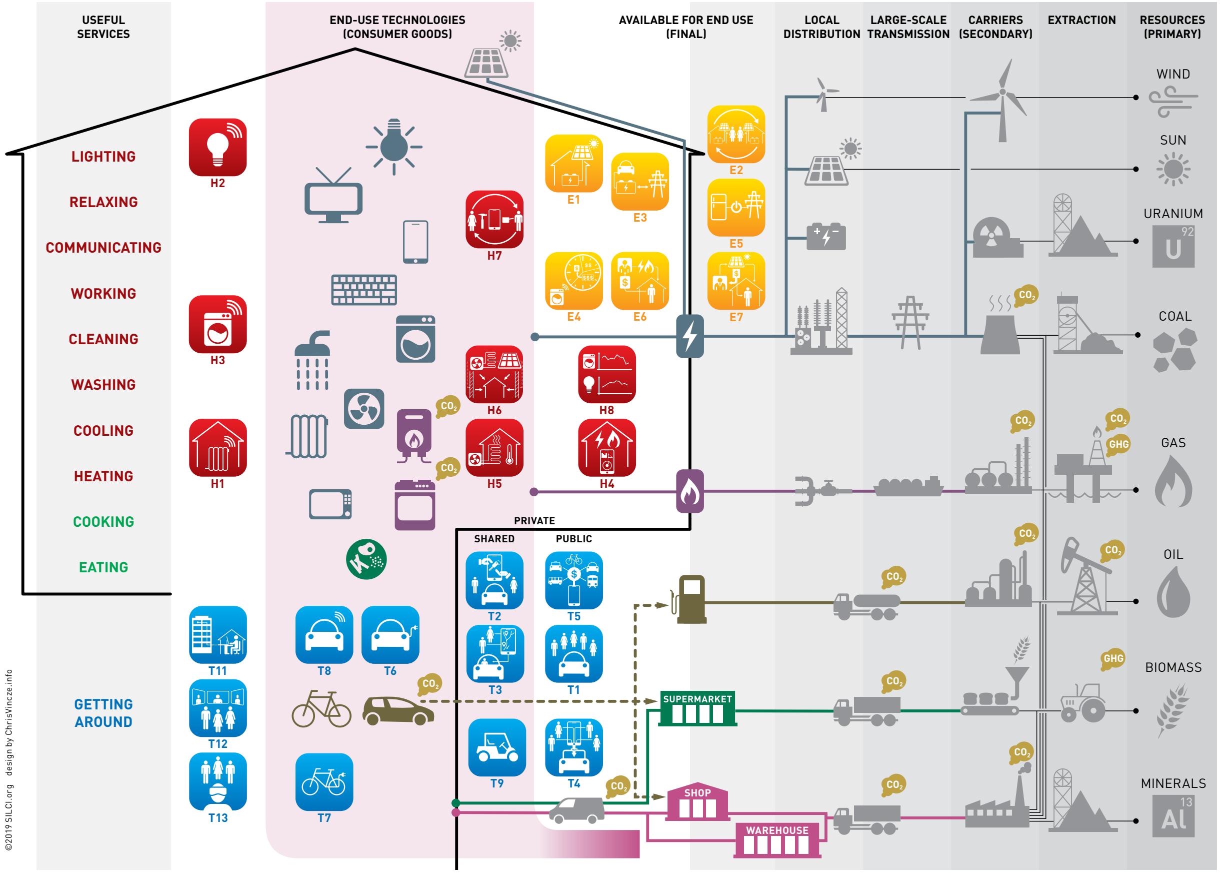
Moving beyond behavioral change narrowly defined, another recent advance has been the introduction of lifestyle concepts to help link explanations of observed behavior across different consumption domains like energy, food, health, and mobility. Quantitative modeling assessments of behavioral and lifestyle change using agent-based and systems modeling techniques are now starting to pioneer endogenous simulations of behavioral change as dynamically co-evolving with economic and technological change.[131] This will strengthen the inclusion of behavioral change with technological change in climate policy design and net zero pathways,[132,133] fostering a new field of inter-disciplinary scholarship on the energy, material, and land requirements for fulfilling human needs—the ultimate purpose of the global energy economy. Eventually, such interdisciplinary research, bringing social and behavioral scientists together with economists and engineers, may help to identify sensitive intervention points for "tipping" social dynamics onto more sustainable trajectories.[134–137]

Figure 4.6. **A Low Energy Demand (LED) scenario in historical context and in comparison to the literature**



Note. Source: Grubler et al. (2018).[124]

Figure 4.7. **Ways in which digital consumer innovations can influence how energy and resources are converted to useful services**



Note. The outline of the home demarcates resource consumption in a private context from shared and public contexts, particularly for transport (blue: e.g., bike and car sharing); homes (red: e.g., smart lighting and home appliances); and energy (yellow: e.g., domestic electricity generation with storage). Source: Wilson et al. (2020).[127] Copyright 2020 by Annual Reviews. Reprinted under the terms of the Creative Commons Attribution 4.0 International License.

The built environment

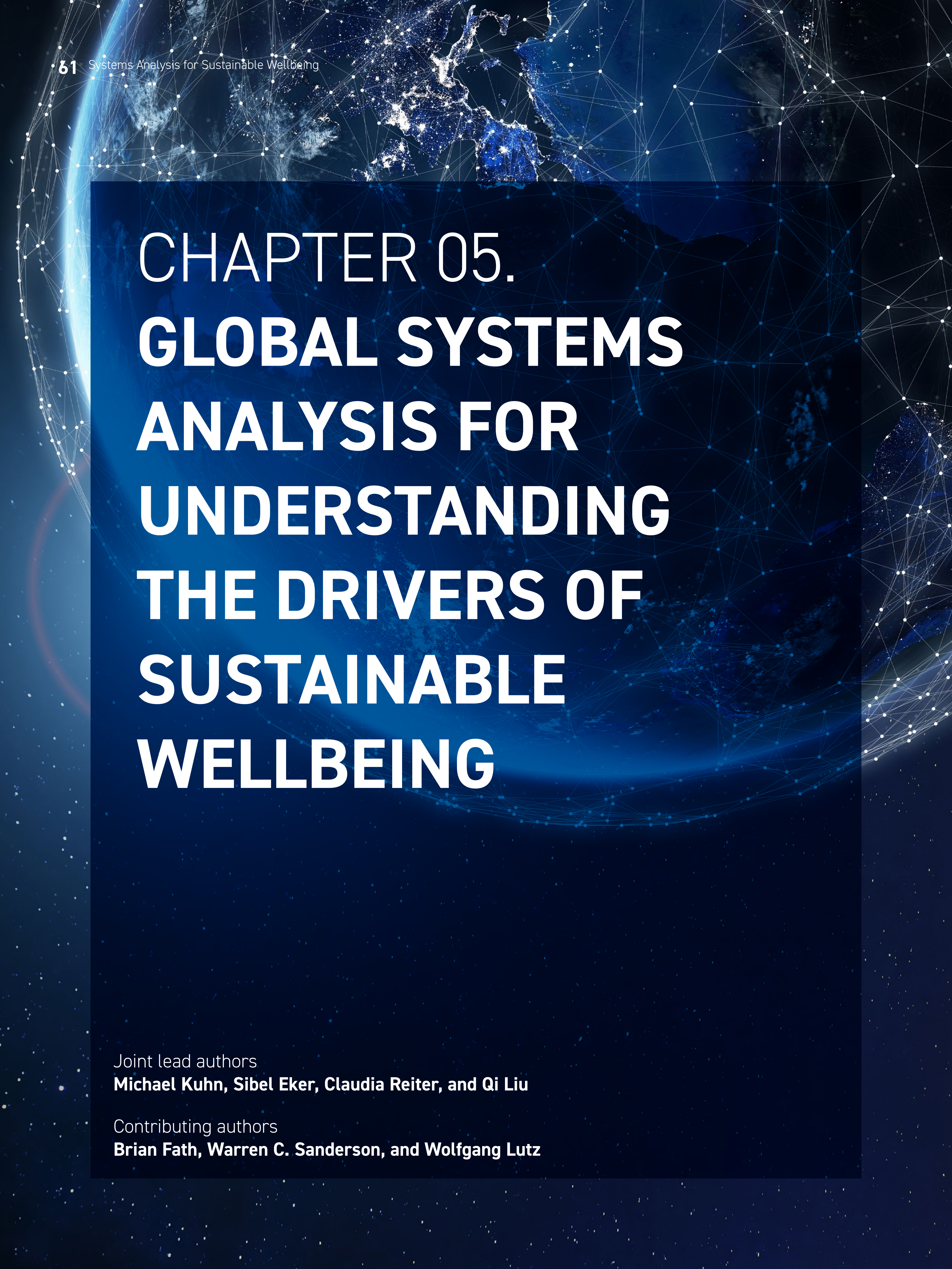
The evolution of the built environment is a key driver of energy and material demands and associated emissions.[138–140] In 2020 the buildings and transport sectors accounted for more than half (55%) of global CO2 emissions,[141] a trend likely to continue under moderate mitigation efforts through to 2050. The built environment influences and is shaped by human behavior, mirroring society's technological and economic development and cultural aspects and it changes over time.[138] Systems analysis tools developed at IIASA, including detailed global sectoral models for buildings (MESSAGEix-Buildings)[49] and transport (MESSAGEix-Transport),[50] have been critical for understanding the state of the built environment and for planning pathways to sustainable futures under changing climates. These models have been applied to investigate mitigation strategies for the buildings and transport sectors through improved representation of human behavior.[50] They have also been used to explore solutions to address heat stress and its implication for energy demands under different socioeconomic and climate scenarios.[142,143] Further efforts are, however, needed to develop approaches that combine knowledge and methods from different domains and disciplines to capture synergies and trade-offs in mitigation strategies. One example would be a consistent modeling methodology for representation of material implications of built-environment changes and their associated emissions.[144] This could support investigations of broader categories of phenomena, including circular- and sharing economies and digitalization, where estimates of their potential contribution to climate change mitigation are uncertain.[145]

Material demands

The production and use of materials in end-use sectors, such as transportation, buildings, and consumer goods, is a significant source of global emissions. Direct CO2 emissions from industries that produce these materials constituted 24% of global emissions and 37% of the global total final energy use in 2018.[146] Production represents only one component of the material life cycle and must be considered in combination with the use-phase and end-of-life phase to determine GHG emissions from industry. Traditionally in energy research, however, cross-sectoral interactions between material stock and flows are not accounted for, nor, too, is how industry satisfies its own final energy demand. IAMs have been used to generate scenarios for assessing energy, industry, and infrastructure transformations. While material cycles and their relationship with energy and the climate are starting to be recognized partially in some IAMs, they have not yet been widely used to represent material cycles and explore circular strategies (extraction, production, manufacturing, use, end of life, waste management).[147,148] To address this challenge, IIASA researchers are currently developing MESSAGEix-Materials, a module that represents material cycles from production to the end-of-life stage within the MESSAGEix-GLOBIOM IAM framework. MESSAGEix-Materials will provide a fully open-source tool for assessing industry decarbonization options under ambitious climate targets for the most energy- and emissions-intensive industries; aluminum, iron and steel, cement, and petrochemicals.[48] MESSAGEix-Materials model is also being linked with MESSAGEix-Buildings and Transport demand-side models to endogenize the material demands of buildings, vehicle stocks, and power generation infrastructure. The model is being developed to become one of the main tools that can be applied to understand the material and energy implications of future demand-side mitigation scenarios and strategies.

Feasibility, governance, and the political economy of transitions

The quality of institutions and effective governance are key enablers in achieving feasible systems and societal transformations. While well understood in political science and economic theory, institutional aspects have not featured prominently in quantitative energy systems models. To bridge this gap, IIASA researchers have recently been developing interdisciplinary approaches that connect political science, political economy, quantitative scenarios, and modeling efforts to enhance the representation of governance and institutional capacities in various contexts.[149] Through this work, insights have been gained into the significant changes in policy frameworks, regulatory mechanisms, and institutional arrangements required for a transition to a low-carbon energy system.[150] Ongoing research is focusing on deepening the understanding of how these factors interact and influence the feasibility and effectiveness of energy transition pathways. By examining successful case studies and analyzing underlying governance structures and policy mechanisms, IIASA research is providing insights into the drivers of, and barriers to, sustainable energy transitions. This research is also exploring the importance of governance and institutions for societies' capacities to adapt to global challenges, with a particular focus on climate change. With further integration of political science, political economy, and quantitative approaches, IIASA scientists aim to enhance understanding of the role played by governance and institutional capacities in shaping adaptive capacity, enabling climate policies, and driving sustainable energy system transitions.



CHAPTER 05.

GLOBAL SYSTEMS ANALYSIS FOR UNDERSTANDING THE DRIVERS OF SUSTAINABLE WELLBEING

Joint lead authors
Michael Kuhn, Sibel Eker, Claudia Reiter, and Qi Liu

Contributing authors
Brian Fath, Warren C. Sanderson, and Wolfgang Lutz

5.1 A short history of global systems modeling (at IIASA)

The golden days of global systems modeling

At the same time as systems theory was being developed in the 1950s and 1960s,[1] Jay Forrester embarked on the endeavor of modeling the dynamics of management, industrial, and urban systems, culminating in the development of the World1 and World2 Earth systems models.[2] These formed the basis of the World3 model, developed by Dennis Meadows, Donella Meadows, Jorgen Randers, and William Behrens III, which underpins the Club of Rome's influential study on *Limits to Growth*[3] and, in updated and extended versions, the follow-up studies *Beyond the Limits*[4] and *Limits to Growth—The 30 Year Update*.[5] The original World3 model includes five modules: i) population and ii) capital, as stocks, which exhibit potentially exponential growth subject to feedback from the other sectors—iii) agriculture, iv) pollution, and v) non-renewable resources—which are subject to limited, or in the case of non-renewables, negative growth. One core conclusion was that the then current trends in population growth and capital accumulation were unsustainable in the light of limited resources but that these trajectories could be changed to sustainable ones, if an early enough policy change were to be instigated. This conclusion was subsequently criticized for wrongly "predicting" resource exhaustion (although prediction was never the intention) at much too early a date. Many of these issues were addressed in updated versions of the model to incorporate emerging environmental, economic, and social trends.[4,5]

Many other systems models of increasing degrees of realism and complexity have been developed since these early days of global systems modeling.[6] At IIASA, the Wonderland model, the PEDA model (see Boxes 5.2 and 5.3), and the FeliX model (discussed in detail in Section 5.3) are just a few examples.

Box 5.1. World systems models

By Brian Fath

A model is a tool, a simplification of reality, to describe key aspects that are deemed relevant to addressing the question at hand. While models can be exploratory, having a clear identification of their purpose will help guide the model development. The first challenge is to pull out those interesting features within a requisite system boundary, leaving other parts of the environment as exogenous: in other words, to determine what is endogenous to the model and what is exogenous. The model will continue interacting and exchanging with its environment through connections carrying inflow and outflow across the system boundary. One consideration for the model is to include enough of the original system to capture the feedback and self-organizing processes inherent in all complex, adaptive systems, typically in terms of production, consumption, and reuse, as seen in an ecological food web model, industrial metabolism, or a socioeconomic system. In that context, a model utilized in systems analysis should not be too narrow in scope.

Any model must carefully consider the dimensions of space and time. The spatial extent is largely informed by the question at hand. Clearly, a global model would include processes and feedbacks spanning the planet's socioeconomic–ecological systems. For example, the first world models, such as World3, included the following subsystems: i) food, ii) industrial, iii) population, iv) non-renewable resources, and v) pollution.

An updated version of such a world model might include additional emphasis on biodiversity and ecosystem services, urban systems and metabolism, governance, and equity. Regarding the temporal dimension, a system dynamics model can simulate into the future, but the time horizon is always constrained by the clarity with which the system processes are known and modeled, and the largely unknown probability that the system switches into a new regime, therefore making the past an unreliable predictor of the future. It is thus more reasonable and appropriate not to see the model simulation outcome as a prediction per se, but as a set of possible scenarios. Or conversely, one can begin with a desirable outcome and back-cast the inputs and decisions likely to reach it, which is a common approach in models involving climate targets.

IIASA has carved out a space dealing with problems that are universal or global, and developing and applying models accordingly. Universal issues are ones that lie within national boundaries, but with which each nation has to deal, for example, education, health care, biodiversity, water supply, housing, etc. Global issues are ones that cross international borders and require global collaboration, for example, energy, climate, food supply, satellite technologies, management of the commons, regulating ecosystem services, etc. In such areas, international cooperation is an important tool for easing tensions by promoting and enhancing science diplomacy.

Finally, a hallmark of systems thinking and system dynamicss models is the goal of capturing causal processes and feedbacks that can lead to better anticipation and possibly avoid or lessen unintended consequences. History is littered with good intentions that went awry due to having too narrow a scope and too myopic a vision—it is not a stretch to say that all current environmental problems are the result of yesterday's solutions, from climate change to ozone depletion to eutrophication. Systems models are the one tool that provides insight, training, and some heuristics to balance and counter this reductionism and promote better decision-making.

Box 5.2. The Wonderland model

By Warren C. Sanderson

The Wonderland model is a global model of the interactions among population, economic development, the environment, and environmental policy. I created this model at IIASA in 1994 to study the processes through which the Earth's environment could collapse, resulting in the loss of a substantial number of human lives.[7]

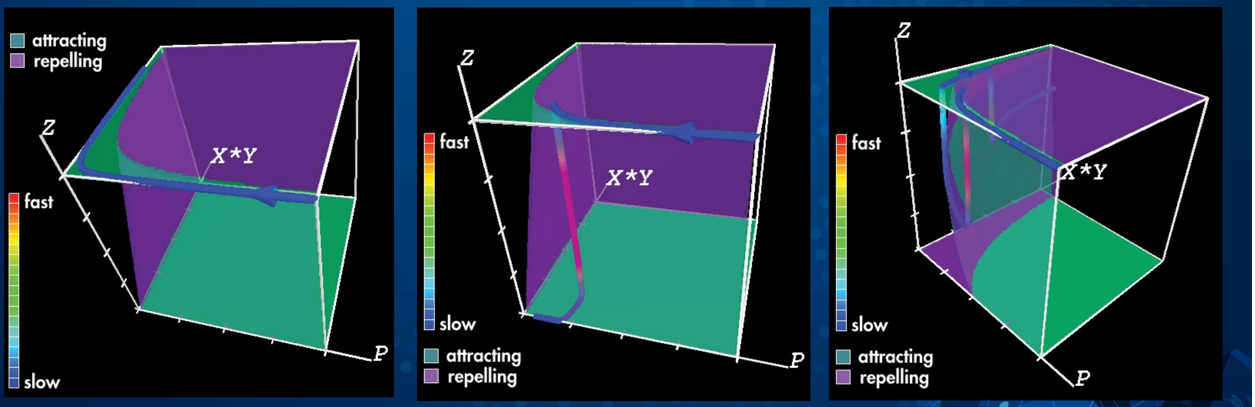
The Wonderland model is extremely simple by design, concentrating on the structure of processes that could lead to an environmental collapse. It is not meant to be predictive. It has only eight equations: two describing an economy affected by environmental conditions, three describing population dynamics and how they are related to environmental conditions, two related to the flow of pollution and how the environment reacts to it, and one related to the costs of policies designed to improve the environment.

Studies of the Wonderland model have elucidated some of its most important analytic features.[8,9] Environmental collapse in Wonderland seemed unpredictable, and two papers investigated that unpredictability. They found analytic expressions for the level of pollution at which environmental stability was lost and the environment would begin to deteriorate, for the time between the loss of environmental stability and the onset of an environmental collapse, and for the level of pollution at the onset of the environmental collapse. These analytic expressions have important implications for understanding environmental collapse. First, when the level of pollution becomes high enough, the environment changes from being stable to unstable. Second, there can be a very long lag between the loss of environmental stability and the onset of an environmental collapse. This period makes the management of environmental problems difficult because during this period, pollution flows can continue to increase with only minor changes in the environment. Third, the level of pollution at the onset of an environmental collapse could be considerably higher than the level of pollution at which the environment first becomes unstable. Reducing pollution at the onset of an environmental collapse to a level consistent with stability may be physically or economically impossible.

An expanded version of the Wonderland model has been used in policy analysis.[10] This version parameterizes it for two regions, OECD and non-OECD countries, adds policymakers with utility functions incorporating environmental quality and economic growth, and parameters relevant for policymaking. Using uncertain model parameters, static and dynamic strategies are developed, which are tested over scenarios similar to the current Shared Socioeconomic Pathways. Three short-run strategies, labeled "Stay the Course," "Slight Increase," and "Crash Effort," have been evaluated. None of these did very well. A dynamic strategy labeled "Safety Valve," which is a two-period strategy where the initial strategy is evaluated at a fixed time in the future and a second strategy is then employed making use of what was learned, did the best. Even using the "Safety Valve" strategy, there are situations where an environmental collapse would still occur.

The Wonderland model supports the application of the precautionary principle in environmental policy. The model shows that rapid degradation in the environment can occur after many years of benign-seeming changes. Policies to avoid environmental collapses must be taken prior to the observation of a strong signal that the speed of environmental deterioration is increasing.

Figure 5.1. **Visualization of the Wonderland model: The slow manifolds and typical trajectories**



(a) Economist's dream scenario

b) Environmentalist's nightmare scenario

(c) Escape sccenario

Plate 3: The slow manifolds and typical trajectories

Note. Source: Gröller et al. (1995).[11]

Box 5.3. The PEDA model, quantifying “vicious circle” dynamics

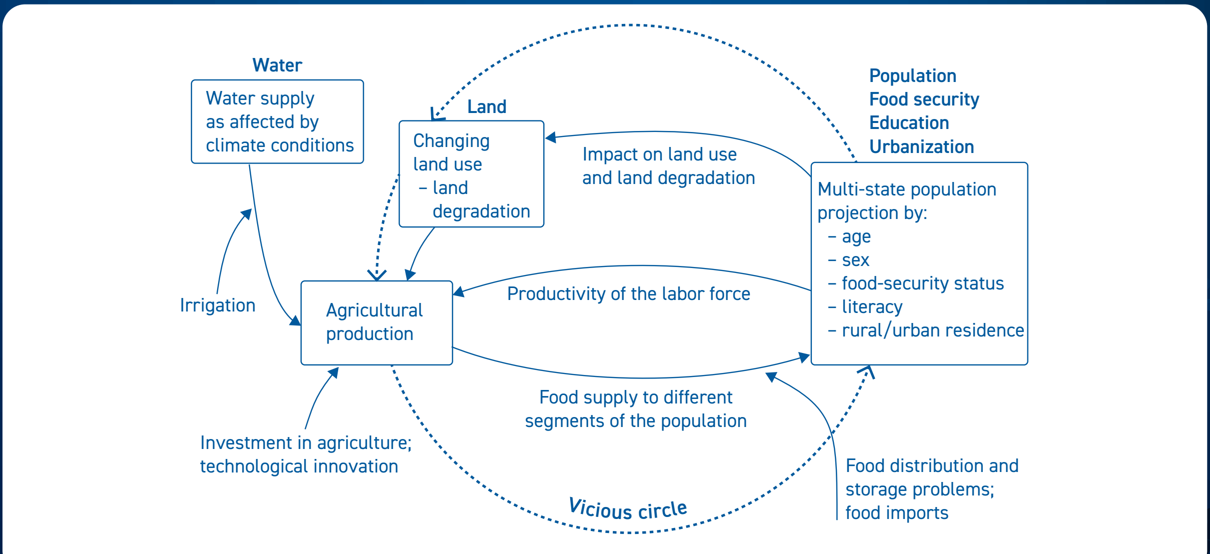
By Wolfgang Lutz

PEDA stands for Population–Environment–Development–Agriculture and is a model developed at IIASA in collaboration with the UN Economic Commission for Africa (UN ECA) to illustrate for governments and stakeholder groups the critical systemic interactions among these factors that are typically addressed independently by different sectors of government. It was developed by Wolfgang Lutz and Sergei Scherbov around the year 2000 and applied to Burkina Faso, Cameroon, Ethiopia, Madagascar, Mali, Uganda, and Zambia.

The PEDA model is based on “vicious circle” reasoning,[12,13] which assumes a dynamic relationship between resource degradation, poverty (food insecurity), and population growth (fertility)—see Figure 5.2. It also includes literacy as a factor affecting both fertility and agricultural productivity. In contrast to other models being used at the time, it also includes two truly innovative features in the form of a fully multi-dimensional population module (differentiating by age, sex, literacy, food-security status and urban/rural place of residence) and by introducing a food distribution function based on a Lorenz curve the shape of which can also be influenced as a policy variable.[14,15]

This model with its country-specific applications for Africa came in the form of user-friendly software that was used in many training workshops and policy exercises for government officials, NGOs, and interested scientists. In addition to the predefined scenarios, users were also able to modify some of the key parameters of the model—corresponding to alternative policy options—and immediately see the long-term consequences of their policy choices.

Figure 5.2. **Basic structure of the PEDA model linking population, food security, and the environment in Africa**



Note. In a vicious circle, high population growth of the rural food-insecure population contributes to degradation of marginal lands. This decreases agricultural production, which in turn increases the number of food-insecure persons. Source: Lutz at al. (2002).[14]

Trials and tribulations

In due course, global systems modeling ran into several challenges of a practical nature, mostly relating to a shortfall of computational power, and also of a conceptual nature. To some extent, these led to deadlock and even abandonment of some of the most ambitious efforts. Richardson[16] discusses eight domains which are crucial for the progress of system dynamics modeling, mostly relating to the advancement of knowledge and practice. In terms of tackling more direct challenges to the modeling, he discusses i) the need for better tools to understand model mechanisms, ii) procedures and standards for confidence and validation, and iii) ways of making models accessible to a wide audience.

Richardson[16] relates his call for a better understanding of model mechanisms to the choice between simple model structures with easy-to-interpret behaviors and more complex structures which, though adding realism, may turn into black boxes. Lutz et al.[14] make a similar point when studying whether key dynamics and insights of the PEDA model can be expressed in a reduced-form way. Indeed, due to their high level of aggregation, many of the global systems models can be read as reduced-form representations of much more complex bio-physical models of Earth systems, and micro-founded agent-based models of the economy, its underlying networks, and its key sectors. While Lutz et al.[14] demonstrate that the reduced-form representation can replicate the dynamics of the more complex PEDA model and thus allows users to "see the forest for the trees," they caution "that there is no forest without trees"; that is, the macro patterns are ultimately generated by individual behaviors. And for effective policymaking, it is important to understand the incentives underlying these behaviors. Ultimately, the choice of model structure and detail should depend on its purpose.[6,17] If the objective is to project the evolution of a global system accounting for the nexus of feedbacks across its subsystems, a global model may well be appropriate. When it comes to an analysis of policymaking, however, where policies have a bearing on behaviors, at least some of the black boxes need to be opened.

Such an approach can easily generate excessive complexity. Considering this, one of the approaches also exercised by IIASA researchers is the soft- or hard linkage of models. Examples of soft linkages include the linkage between IIASA's Model for Energy Supply Strategy Alternatives and General Environmental Impact (MESSAGE) with the Greenhouse Gas–Air Pollution Interactions and Synergies (GAINS) model to account for air pollution impacts, and the Global Biosphere Management Model (GLOBIOM) to account for emissions from land use.[18] Strikingly, such approaches may also benefit from global systems models that are employed as emulators of the more complex modeling framework and thereby allow for a means of cross-checking outcomes at an aggregate level.

The development of tools and frameworks that facilitate the understanding and validation of models belongs to the domain of modeling methodology as opposed to implementation methodology.[19] As regards the latter, soft system–analytic approaches toward stakeholder involvement, co-creation and nexus modeling have recently been developed and are increasingly deployed, with some pioneering work carried out at IIASA.[20] Here, reduced-form global systems models have the potential to foster systems thinking among stakeholders and structure the development of joint scenarios that keeps sight of both the forest and the trees, metaphorically speaking.

Finally, global systems models, which are both comprehensive in capturing inter-systems linkages and reduced in terms of intra-systems mechanisms, can be excellent sandboxes for the exploration of the macro-level ramifications of new concepts, research questions, and policy scenarios.

A way forward

In summary, we can identify four roles for global systems models: i) as macroscopic tools to identify emergent patterns of systems that are difficult to trace from detailed close-up models; ii) as emulators of clusters of close-up models, which allow us to step back from sectoral models and have a look at the total to check for plausibility and coherency; iii) as illustrators of key systemic processes in stakeholder processes; and iv) as exploratory tools for new approaches and computational analyses in systems modeling within comparatively simple yet comprehensive settings.

The exploratory function of a global systems model is what we will be drawing on in the remainder of this chapter. Specifically, we aim to incorporate into a system dynamics model the notion of human wellbeing as the outcome of demographic, social, economic, and environmental development, measuring its evolution within the model in a comprehensive and rigorous way, and assessing how it varies across the population and over time alongside different scenarios.

5.2 The case for including wellbeing measures in global systems models of sustainable development

In the last five decades, numerous institutions and researchers worldwide have participated in the advancement of human wellbeing indices. The explicit aim of these efforts is to assist governments in formulating effective policy interventions for enhancing quality of life across diverse national and cultural settings.[21] Up to the present, by far the most prominent and widely used wellbeing indicator continues to be GDP per capita. Yet, after heavy criticism of the concept, the majority of modern wellbeing indices look beyond the measurement of national income and attach greater attention to social and ecological dimensions of human development, including social capital, governance, civil liberties, and environmental quality.[22–24] Many of these recently proposed indicators aim at one composite metric, which incorporates a multitude of these different dimensions, with prominent examples being the Human Development Index,[25] the OECD Better Life Index,[26,27] the Decent Living Standard,[28] and the Social Progress Index.[29] While also being multi-dimensional in nature, the Years of Good Life (YoGL) indicator, as described in greater detail in Section 5.4, differs from the previously mentioned indices, as it is a fully integrated measure that can stand alone, has substantive meaning in its own right, and can easily be broken down for different population groups without being constrained by national accounting frameworks. A detailed derivation and application of YoGL, as well as a comparison between YoGL and other existing wellbeing indicators can be found in Lutz et al.[30]

Ever since the 1987 Brundtland report *Our common future,* sustainable development, defined as "meeting present needs without compromising future generations' ability to meet their needs," is linked to the wellbeing of distinct present-day and future generations.[31,32] Against this backdrop, it is striking that, while several global systems models generate the Human Development Index as an outcome (e.g., FeliX, IMAGE, IFs), the broader wellbeing implications of sustainable development pathways at the population level have rarely been assessed in a rigorous way. One notable recent exception is the Earth4All model,[33] which has been developed as a much enriched and updated successor of the *Limits to Growth* models and explicitly includes an Average Wellbeing Index (AWI). The AWI is a weighted mean of five components: worker disposable income; public spending per capita; the ratio of owner-to-worker income as a measure of inequality; observed global warming as a measure of environmental-related wellbeing; and the rate of growth in the AWI over the past five years as a measure of perceived progress. While this index captures many important dimensions of wellbeing, it is nevertheless highly aggregative and somewhat arbitrary in its composition. In particular, it is only indirectly linked to the population as the ultimate subject of wellbeing, and for that reason does not allow the detailed analysis of the emergence of wellbeing across the subgroups of a population that would be at the heart of an analysis of sustainable and fairly distributed wellbeing for the human population.

Modeling objective, approach, and findings

For a demonstration of how the evolution of wellbeing *across and within cohorts of a population* can be incorporated into a global systems model, we amend in the remainder of this chapter the Full of Economic-Environment Linkages and Integration dX/dt (FeliX) system dynamics model, which was developed at IIASA, as follows. We begin by modifying the model to take proper stock of the evolution of educational attainment across the cohorts of the population and across genders as a driver of fertility, longevity, and economic productivity (Section 5.3). We subsequently introduce the YoGL indicator of wellbeing into the FeliX model to map consistently the impact of development pathways on wellbeing, as channeled through changes in longevity and the shares of the population who are out of poverty and meeting basic standards in terms of health and cognition (Section 5.4). Based on these model enrichments to capture major aspects of demography and wellbeing, we call the resulting framework the DEMOFeliX model. The model extension is followed by the characterization of three baseline development scenarios (reference, optimistic, and pessimistic) and the description of a female empowerment policy scenario in Section 5.6. Results on policy impacts across the three baseline scenarios on human wellbeing are then presented in Section 5.7, and conclusions are drawn in Section 5.8.

5.3 Modeling education, poverty, and health in the DEMOFeliX model*

Brief introduction to the original FeliX model

The FeliX model is a globally aggregated, feedback-rich simulation model of climate, economy, environment, and society. It captures the core physical and anthropogenic mechanisms of global environmental and economic change within and between economies, energy, carbon cycle, climate, biodiversity, water, population, and land use. The development of FeliX started during 2006–2009 at IIASA in the European Union–funded GEO-BENE project to support global Earth observations. Since then, the model has been used to assess the socioeconomic and environmental impacts of Earth observation improvement,[35,36] carbon cycle impacts of global emission pathways,[37,38] and the population dynamics of shifts to sustainable diets.[39] In recent years, the need to analyze synergies and trade-offs among sustainable development goals (SDGs) has attracted attention to feedback-rich models that can capture the broad scope and interactions of the SDGs. In line with such research gaps, FeliX has also been used to investigate the sustainable development pathways based on an endogenous analysis of SDG synergies and trade-offs,[40] and specifically to analyze the trade-offs between environmental pressures and eradication of global poverty.[41]

FeliX is an empirically grounded, easily traceable system dynamics model that has low computational requirements and can hence be used in large uncertainty analyses and interactive stakeholder engagement. Instead of techno-economic detail at a high level of resolution, FeliX is geared toward running what-if analyses of cross-sectoral feedbacks, which are depicted in Figure 5.3. Those cross-sectoral feedbacks include the major human-Earth system interactions, such as the climate impacts of energy and land use, the environmental impacts of water and fertilizer use, and the feedback of climate damage and environmental degradation on economic growth, crop yields, and human mortality. More detailed information on the modules can be found in the model documentation[34] and on the FeliX model description page (https://iiasa.ac.at/models-tools-data/felix).

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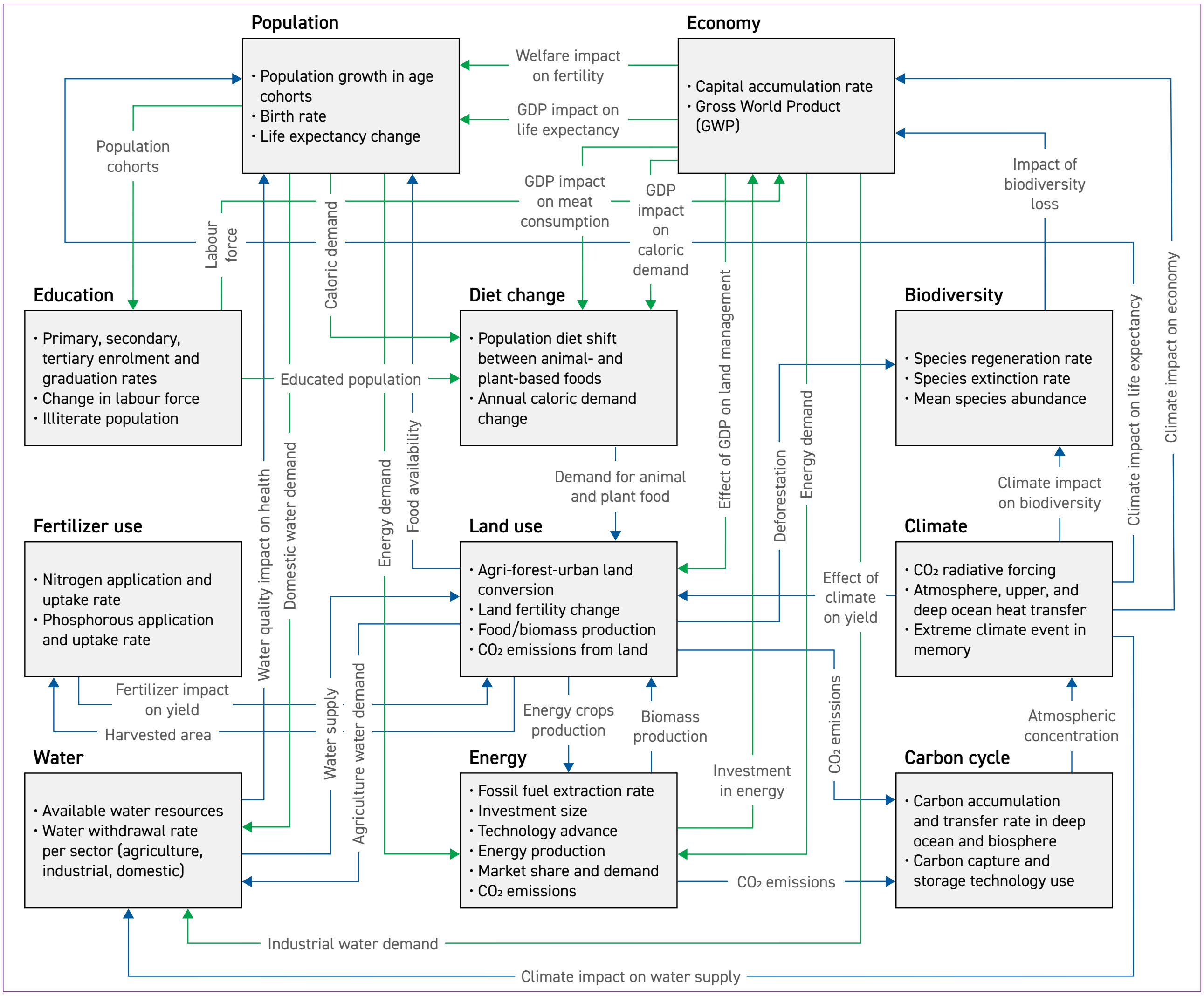
* Technical Note: The DEMOFeliX model is fully documented in a IIASA Working Paper.[34] The paper also describes the considerable potential of the model for further development in terms of alternative policy scenarios, regionalization, and more in-depth analysis of the channels through which policies have a bearing on long-term wellbeing.

Figure 5.3. **Overview of the FeliX model**



Note. Boxes show the main modules and summarize their components, and links refer to the interconnections between them. Source: Moallemi et al. (2022).[40] Adapted under the terms of the Creative Commons Attribution 4.0 International License.

Accounting for the role of education and human capital in the DEMOFelix model

As discussed in Chapter 2, and as will be further highlighted in Section 6.2, extensive research shows that education is an essential prerequisite for humanity's most important aspirations, including health and avoidance of premature death,[42–48] ending poverty and hunger,[49–52] improving institutions and participation in society,[53,54] fostering economic growth,[51,55,56] and enhancing adaptive capacity to already unavoidable climate change.[57,58] To account for the key role of education for global sustainable development, important adjustments have been made to the population, education, and economy modules of FeliX.

While a detailed description of the population module is given in the model documentation,[34] here we will provide only a brief overview of the major adjustments to the population, education, and economy modules of FeliX implemented within this project. In line with previous findings showing that educational attainment should be routinely added to age and sex as a third demographic dimension,[59–61] in DEMOFelix both fertility and mortality in the endogenous population module are determined by level of education, thus reflecting empirical evidence. Total fertility is formulated as a multiplicative function of Gross World Product (GWP) per capita and *mean years of schooling*, hence preventing a strong assumption of the monotonic dependence of fertility solely on economic growth or education. Furthermore, to provide a more accurate and nuanced understanding of fertility, the current FeliX model incorporates age-specific fertility rates, moving away from relying solely on overall birth rates. As regards mortality, life expectancy at birth is now additionally determined by mean years of schooling and by temperature increase (to account for climate change) in addition to GWP per capita and total food supply per capita.

The resulting population size at different age cohorts feeds back into the education module to compute the population of primary, secondary, and tertiary education graduates through enrollment rates and graduation rates. This module represents the size of population with each educational attainment level as a stock chain to account for the aging of people who graduate from each level and the transitions between the education levels. Therefore, primary, secondary, and tertiary education graduates are represented by a stock variable for each gender and 5-year age group corresponding to the education level. Mean years of schooling are then formulated as the population-weighted average of the duration of each education level. Enrollment rates are formulated as endogenous variables dependent on economic growth.

Production of GWP and labor force composition

Gross world production (GWP) is calculated by total reference economic output (REO), adjusted for the impact of climate change and biodiversity. The total REO is the sum of the REO generated by the skilled and unskilled labor force and determined according to a Cobb-Douglas production function, depending on the technology and capital allocated to the skilled/unskilled labor force and the size of this labor force. Technology and capital follow exogenous trends, determined by the model calibration. We assume that the size of the skilled labor force is the sum of the total population aged 15–64 with tertiary education, and half of the population aged 15–64 with secondary education, multiplied by the labor force participation rates of the respective groups. The size of the unskilled labor force is determined by the remaining population aged 15–64 and the corresponding labor force participation rates.

Conceptualization of poverty

The global poverty rate is defined as the proportion of the population aged 15+ living below the international extreme poverty line ($2.15 per capita per day in 2017 PPP). In the calculation of poverty rates, we follow Fosu,[62] Lakner et al.,[63] and Liu et al.[41] and assume that income follows a log-normal distribution as characterized by the mean and standard deviation of income. Here, the mean income can be calculated from the per capita income and the Gini coefficient within each population group, while the standard deviation of income can be calculated from the Gini coefficient. Finally, we obtain the per capita income within each age and gender group as a function of global warming potential and the respective Gini coefficients based on the relative income of the skilled as opposed to the unskilled. Further details on the modeling of GWP and poverty can be found in the model documentation.[34]

5.4 Wellbeing in the DEMOFeliX model

To consistently account for the evolution of wellbeing, we extend the FeliX model to implement the Years of Good Life (YoGL) indicator as a wellbeing measure. YoGL was developed by Lutz et al.[30] and aims to estimate the remaining years of life an individual can expect to live in a "good" state. By considering the changing characteristics of human populations that reflect the overall wellbeing of society, YoGL is specifically designed to assess the sustainability of long-term development trajectories.[64]

YoGL is built on the fundamental assumption that individuals experience any quality of life only if they are alive. Recognizing that mere survival alone is insufficient to capture wellbeing, however, YoGL is contingent upon meeting minimum standards of both objectively observable conditions (capable longevity) and subjective life satisfaction. Drawing on earlier works by Desai, Sen, and Boltvinik,[65] the objective conditions measuring "capable longevity" are further divided into three dimensions: i) being out of poverty, ii) being cognitively enabled, and iii) being physically healthy. To be considered as "good" years in the YoGL calculation, individuals must surpass critical thresholds in all three objective dimensions and report a minimum level of overall life satisfaction, thus bridging the divide between those who only accept subjective indicators versus those pointing to the need for objective criteria. In YoGL, years of life are only considered as "good" if people are above critical thresholds on both objective and subjective grounds.

In previous empirical applications of YoGL,[30,66,67] the population share above critical thresholds in all YoGL dimensions is derived from individual characteristics, as measured in representative cross-sectional surveys. In a global macro model such as FeliX, however, a different approach is required to capture the YoGL components and project the future prevalence rates. The three objective YoGL dimensions are therefore assumed to be endogenous variables, generated by direct and indirect impacts and feedbacks within the different FeliX modules (see model documentation[34] for more details). Subjective life satisfaction is not considered in the current version of DEMOFeliX due to lack of data at the global level.

Human Development Index as an alternative welfare measure

To provide a contrast, we also report the temporal dynamics of the HDI, based exclusively on objective indicators. The HDI is a capabilities-oriented index consisting of life expectancy at birth as a measure of health; the average of expected and mean years of schooling[68] as a measure of education; and GWP per capita as a measure of resources.[25]

5.5 Baseline scenarios

To take the uncertainties of environmental change and human responses into account and to explore the implications of these varying futures for the evolution of wellbeing, we consider three baseline scenarios. These come from the Shared Socioeconomic Pathways (SSPs) scenarios, as described in Chapters 2 and 4:

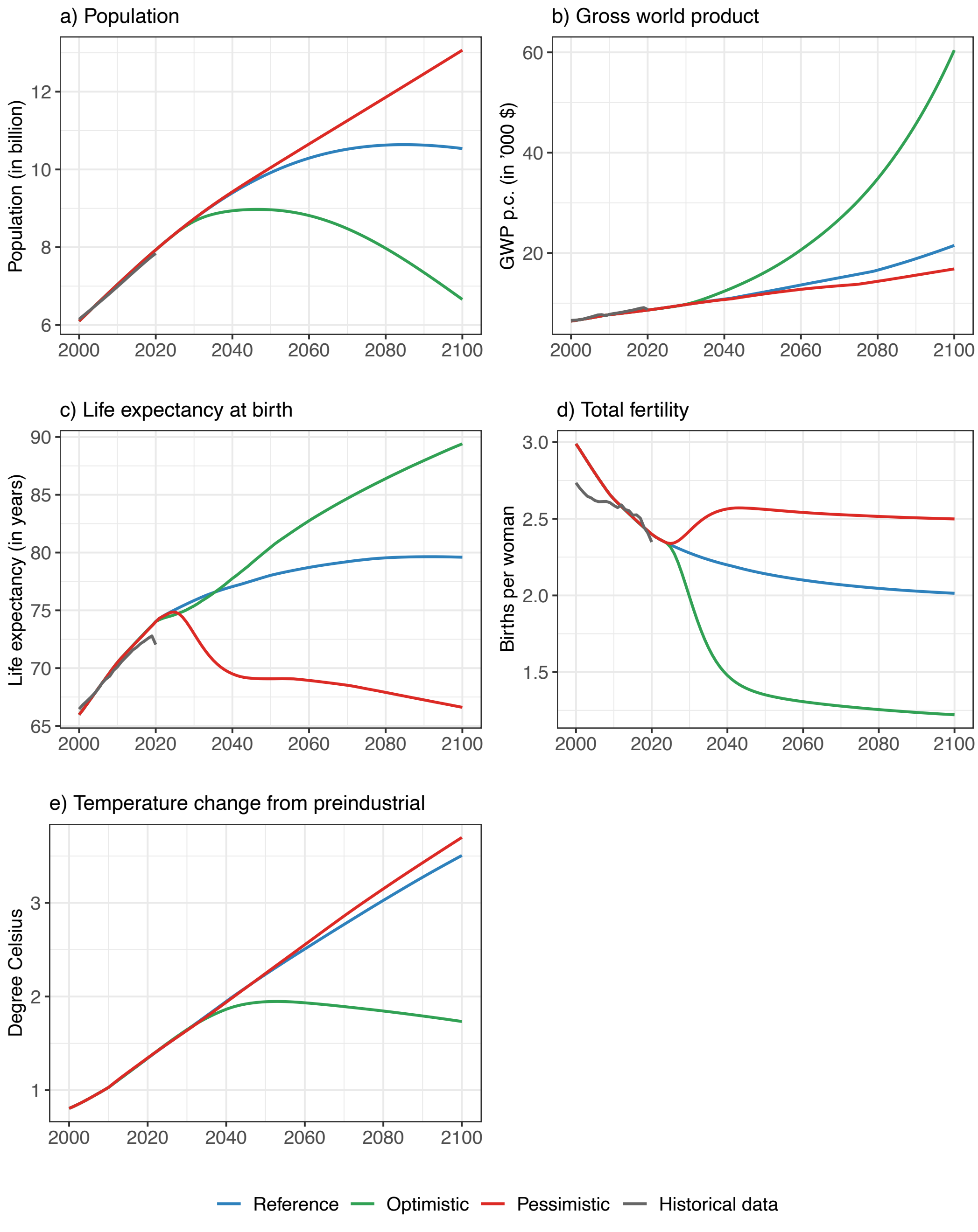
- **Reference scenario:** follows the **SSP2** (middle of the road) narrative for energy, land use, food, and climate policy,[69] as calibrated in Moallemi et al.[40] Demographic indicators follow the SSP2 projections, too, except for the climate impact on mortality which leads to lower life expectancy projections than does the SSP2 narrative. Climate impacts on mortality rates are incorporated into the model using the temperature- and education-dependent estimates of Bressler et al.[70] In contrast to the original SSP2 projections, GWP per capita is also endogenously projected based on labor force, technological progress, and capital investments. It takes the climate damage to economic output into account based on the empirical damage function estimated by Burke et al.[71] for long-term impacts of a given temperature increase across all regions and income levels pooled.

- **Optimistic scenario:** follows the **SSP1** narrative (green road with low challenges to mitigation and adaptation) for energy, land use, food, climate policy. The narrative for population and education follows SSP1, with the exception of climate mortality and climate damage function on economic output, as described for the reference scenario. The eventual climate impact on economy and mortality depends on the temperature projection created by this narrative. In addition, this scenario assumes that technological progress in the non-energy sector will be 50% higher in 2100 as compared to the reference scenario, reflecting possible spillovers from rapid technological change toward a greener economy.
- **Pessimistic scenario:** follows the **SSP3** narrative (regional rivalry with high challenges to mitigation and adaptation) for energy, land use, food, climate policy. The eventual climate impact on economy and mortality depends on the temperature projection created by this narrative. This scenario assumes that technological progress in the non-energy sector will be 50% lower in 2100 compared to the reference scenario, reflecting possible negative impacts on technological progress in a world that remains heavily reliant on fossil-related technologies and is subjected to stronger climate damage.[72]

Figure 5.4 depicts the outcomes in terms of global population and GWP per capita across the three scenarios for the hundred-year time span 2000–2100 (a comparison of the baseline scenarios to the SSP projections can be found in the model documentation[34]). Population reaches 10 billion around mid-century in both the reference and pessimistic scenario, whereas it peaks at 8.9 billion at the same time in the optimistic scenario. GWP growth is positive in all scenarios, but the strong climate damage and loss of biodiversity in the reference and pessimistic scenarios impose a sizable drag on growth and leave the global average GWP per capita at around US$20,000, as opposed to $60,000 in the optimistic scenario. The stabilizing population in the reference scenario is attributed to the stabilizing values of global life expectancy and total fertility rates, whereas the low fertility, induced by increasing educational attainment and economic growth, outperforms the high life expectancy and leads to low population in the optimistic scenario. Notably, life expectancy can keep increasing only in the optimistic scenario, where the climate impacts on mortality are significantly reduced by strong climate action and increasing education levels.

Economic growth is accompanied by an educational expansion, as depicted by the global total number of tertiary graduates and mean years of schooling. Here, the optimistic scenario features a higher growth of tertiary graduations, which reaches 3.65 billion people by 2100 and can be traced to an earlier and stronger shift in the educational distribution from primary toward tertiary education. In the pessimistic scenario though, educational expansion is halted. As discussed in more detail in the model documentation,[34] global poverty is curbed in all scenarios, with the pessimistic scenario still resulting in a global poverty rate of 7% by 2030.

Figure 5.4. **Projections of global population**



Note. (a), Gross World Product (GWP) per capita (b), life expectancy at birth (c) and total fertility rate (d), global mean temperature change from preindustrial times (e), in the three baseline scenarios. Historical data (black line) is obtained from the Wittgenstein Centre Data Explorer[73] for all demographic variables and from the World Bank[74] statistics for GWP (GDP) per capita.

5.6 Female empowerment as policy scenario

There is an increasing recognition that female empowerment is a strong driver of sustainable development.[19,75] This includes direct effects of female empowerment for economic development;[76–79] the impact of female health on (female) education and economic development;[80,81] the impact of female employment opportunities on female empowerment;[82] the impact of female empowerment[83] on democracy; and the impact of female political representation on maternal mortality and education.[84,85]

To capture key dimensions of female empowerment in terms of education and labor market participation, we additionally define a policy scenario based on the assumption that implemented policies will have the following effects by 2030: (a) Female enrollment in primary and secondary education doubles; (b) Female labor force participation increases, reaching 94% in 2030 for women aged 25–54, and 67.5% for women aged 55–64; (c) Quality of secondary education increases, with "skilled" secondary graduates increasing to 60%. This policy scenario is superimposed on all three baseline scenarios, allowing us to study the impact and leverage of such an empowerment policy package.

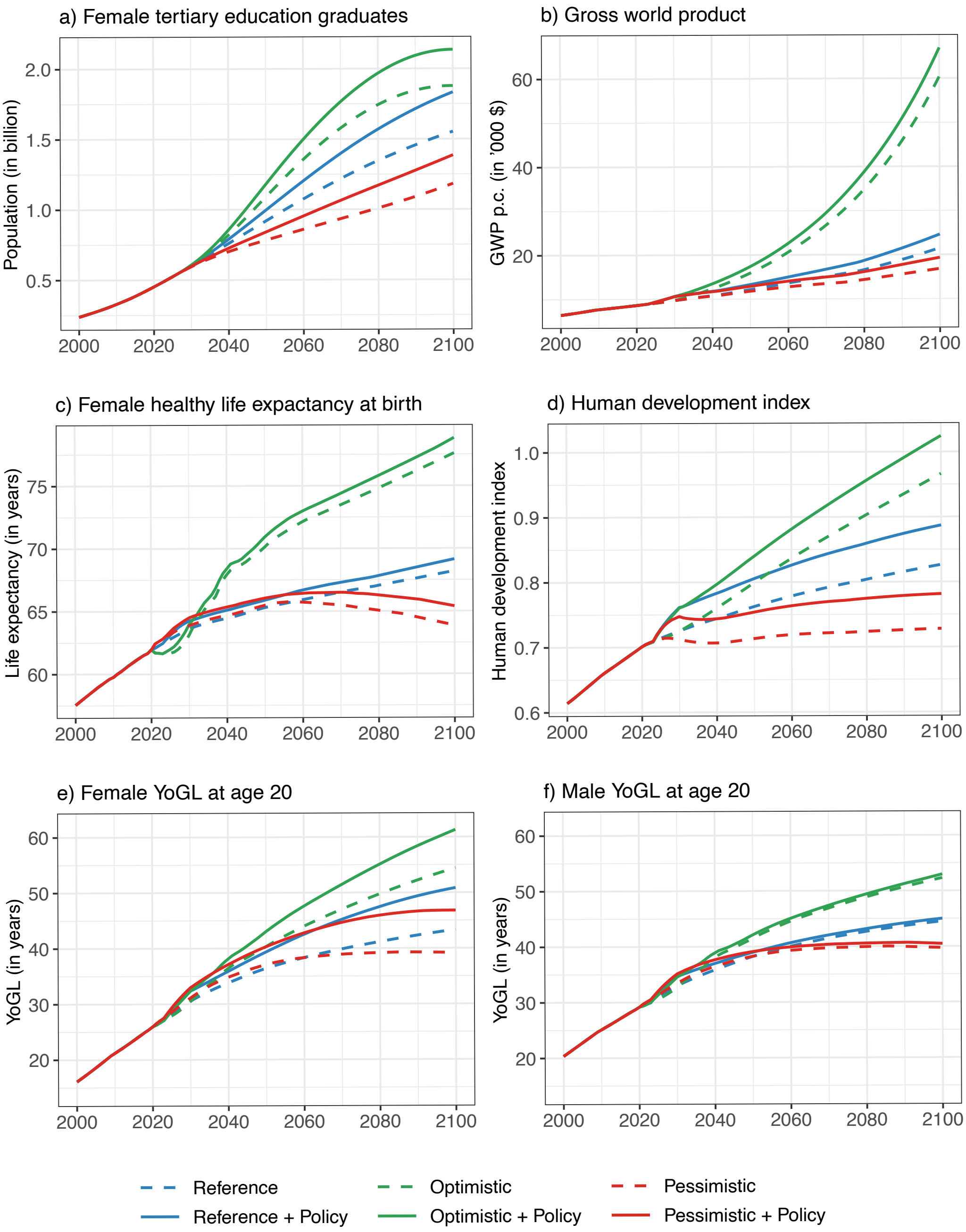
5.7 Main findings and policy implications

Figure 5.5 summarizes key results when the impact of the empowerment policy package across the three scenarios is considered. Adding the policy package results in a sizable increase in the mean years of schooling across all baseline scenarios. Combined with the expansion of the female labor force participation, the educational expansion leads to a sizable increase in GWP growth across all scenarios. While the absolute gain is largest in the optimistic scenario, the policy package has the strongest impact in the pessimistic scenario in relative terms, raising GWP by about 15% despite the high climate damage. Notably, the strengthening of education and labor market opportunities for women comes with a significant advancement in the reduction in global poverty. This is by directly eradicating poverty among unskilled women, with additional GWP growth only playing a secondary role. Female empowerment also results in a visible increase in healthy life expectancy across all scenarios.

Global wellbeing as measured by YoGL increases under all baseline scenarios, albeit at different rates. The increase is more marked for the optimistic scenario, while the pessimistic scenario shows stagnation and even a minor decline in YoGL from 2060 onwards. Under all baseline scenarios, YoGL is on average lower for women than for men, tending toward a male wellbeing advantage. The difference is largest in the pessimistic scenario, while it dissipates and eventually reverses in the optimistic and the female empowerment policy scenario. Compared to the HDI, YoGL increases by on average about twice the rate, indicating important differences in the measurement of wellbeing progress across the two indicators.

Both the HDI and YoGL increase with policies toward female empowerment. While the policy raises the HDI by about 6–7% by 2100, it boosts female YoGL at age 20 by some 7 years to between 61 years in the optimistic scenario and 50 years in the pessimistic scenario, amounting to a 12% and 19% increase, respectively. Here, it is notable that female empowerment yields substantial gains in all scenarios alike, implying that female empowerment is a "robust" policy approach toward welfare improvements, regardless of the underlying development of the world. Moreover, given that the relative gains are somewhat larger in the pessimistic scenario, female empowerment can be viewed as a strategy that enhances resilience. This finding is consistent with earlier work which has shown that increasing educational attainment can have substantial benefits for wellbeing, as measured by the HDI, and reducing vulnerability to climate impacts.[87] Finally, we note that with gains to male YoGL being much more modest, the female empowerment package also leads to a reversal of the gender gap in YoGL by 2100, essentially reflecting the male disadvantage in life expectancy.

Figure 5.5. **Overview of policy impacts across the baseline scenarios for selected indicators**

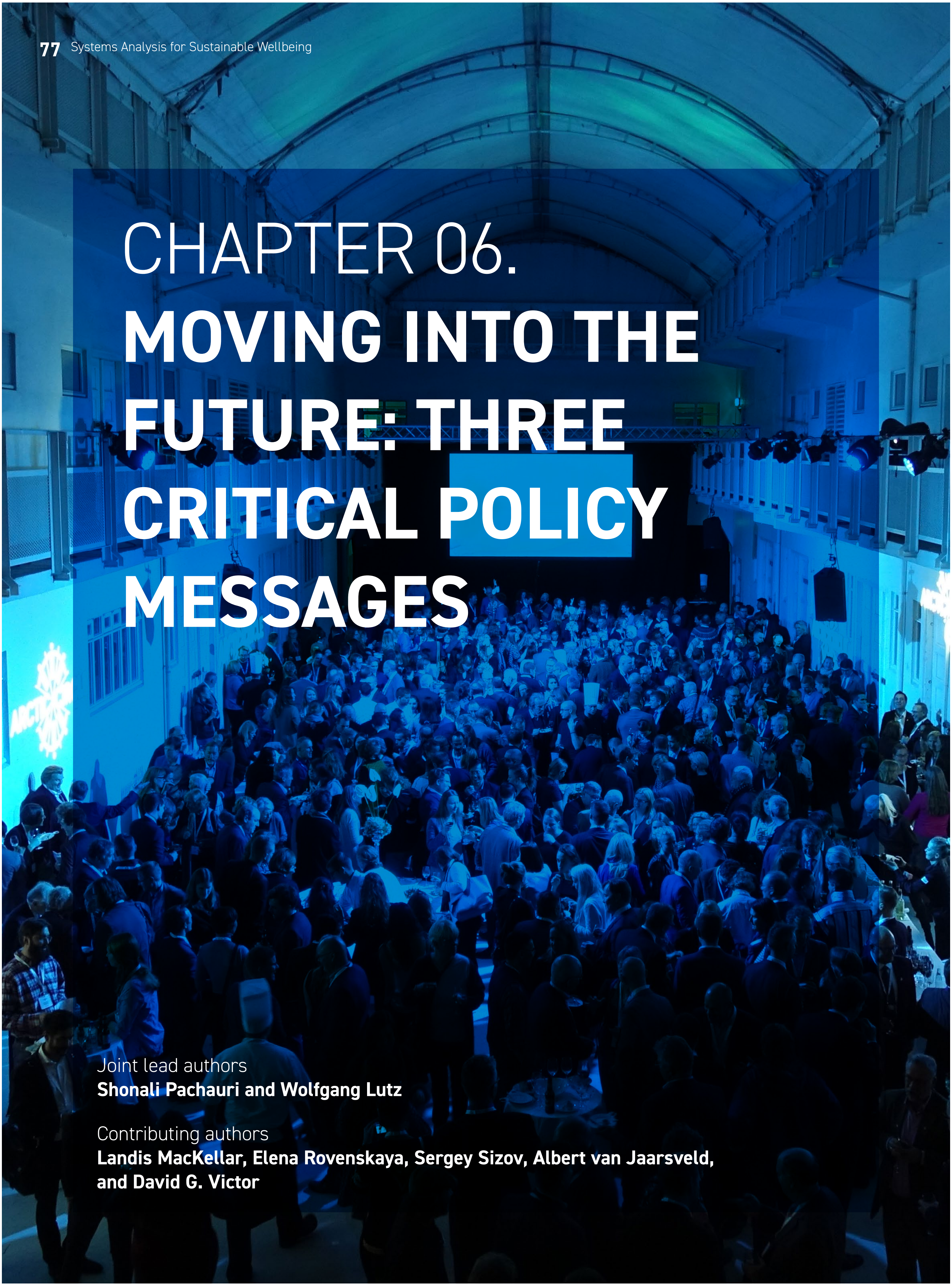


Note. (a) Women with tertiary education; (b) Gross World Product; (c) Female healthy life expectancy at birth; (d) Human Development Index; (e) Female YoGL at age 20; (f) Male Years of Good Life at age 20. The data and projections for the demographic indicators are from the Wittgenstein Centre's updated SSP2 projections.[86] Data for GWP per capita and the global poverty rate is from the World Bank.[74]

5.8 Toward a sustainable wellbeing agenda

Global systems modeling has a 50-year history at IIASA, with Jay Forrester's World Model having been published just one year before the founding of IIASA in 1972 and substantial parts of the model's further development having taken place within the IIASA network. While global systems modeling has met several conceptual and pragmatic challenges along the way, it continues to play a role in an emulator/model-linking function; an illustrator function; and an exploratory function. This chapter draws on the latter two in further developing a global systems model to study the evolution of sustainable wellbeing. This constitutes an innovation for systems modeling, which so far has been insufficiently applied to sustainable development from a wellbeing perspective.

When searching for an impactful policy trigger, our results indicate that female empowerment, in particular through the expansion of female education and labor force participation, has multiple benefits, including enhancing economic growth, longevity, and physical and cognitive health. By shifting women who are particularly at risk of poverty out of the low-skilled group, global poverty can be curbed much earlier than in the baseline scenarios. All these mechanisms substantially enhance welfare as measured by YoGL, a finding that holds regardless of whether the baseline development trajectory is "optimistic" or "pessimistic." We thus find strong confirmation from a system dynamicss perspective that female empowerment should, indeed, be a key component of any sustainable development agenda.



CHAPTER 06.

MOVING INTO THE FUTURE: THREE CRITICAL POLICY MESSAGES

Joint lead authors
Shonali Pachauri and Wolfgang Lutz

Contributing authors
Landis MacKellar, Elena Rovenskaya, Sergey Sizov, Albert van Jaarsveld, and David G. Victor

Over its five decades in existence, IIASA has influenced policymaking at many different levels and in several different ways. The word "Applied" in its name was consciously chosen by IIASA's founding fathers—only men were involved at this stage—to signal that the most advanced and powerful methodological tools of systems analysis should not be developed for their mathematical elegance alone but also to help address and resolve the complex real-world problems affecting humanity.

IIASA's contributions have mainly been published in the form of scientific reports in leading peer-reviewed journals and scientific books that meet the highest standards in both disciplinary and inter-disciplinary research. Many of these studies, which have focused on topics chosen for their potential applicability to complex problems of a global or universal nature, are listed in this report and in the time-chart of IIASA highlights at the end of the volume. Many of their most relevant findings have been widely disseminated to policy audiences in the form of science-based policy briefs and through the extensive network of IIASA's National and Regional Member Organizations and have influenced policy processes around the world. This form of science diplomacy has, in fact, been a core part of IIASA's work since the beginning (see Box 6.1).

Since the establishment of IIASA, thinking on global development has changed, moving from an almost exclusive focus on GDP growth—and the belief that such economic growth will contribute to eliminating poverty—to an understanding that economic growth tends to be linked to ecological and environmental damage;[1–4] and moreover, that ever-more consumption does not bring ever-rising life satisfaction, happiness, or wellbeing.[5,6] Calls for "moving beyond GDP"[7] and perpetual economic growth as the goal for society have gained strength. A rich diversity of alternative ideas have been put forward, from the 1972 pioneering study on *Limits to Growth* to more recent proposals on regenerative economics,[8] doughnut economics,[9] de-growth,[10] and a wellbeing economy.[11] While each idea is distinct, their shared aim is to ensure wellbeing for all and to see humanity flourishing on a regenerated, vibrant, and resilient planet.

The 2030 Agenda for Sustainable Development adopted by the UN Member States in 2015 with its central, transformative purpose of "Leave no one behind" reflects this change in development priorities. Adding urgency have been environmental concerns, spearheaded into prominence by the 1987 *Brundtland Report* and now integrated with the development agenda. The ambition of the 17 Sustainable Development Goals (SDGs) is to tackle multidimensional and interacting inequalities by enhancing people's capabilities and ensuring that everyone has equal access to opportunity and choice, while at the same time protecting the environment and planet. Progress toward achieving the SDGs, however, has been unsatisfactory, and it is recognized that their aims are in grave jeopardy today.[12]

As we pass the halfway mark of the 2030 Agenda, there are several lessons to be learned. Much has been written about specific solutions to accelerate progress on individual SDGs and potential synergies and trade-offs among them, which will not be reproduced here.[13–16] As a conclusion to this report, however, we present three key messages as a starting point for discussions about a post-2030 Agenda. We believe that action on these messages is critical if we are to overcome existing obstacles and accelerate transformation toward sustainable wellbeing for all.

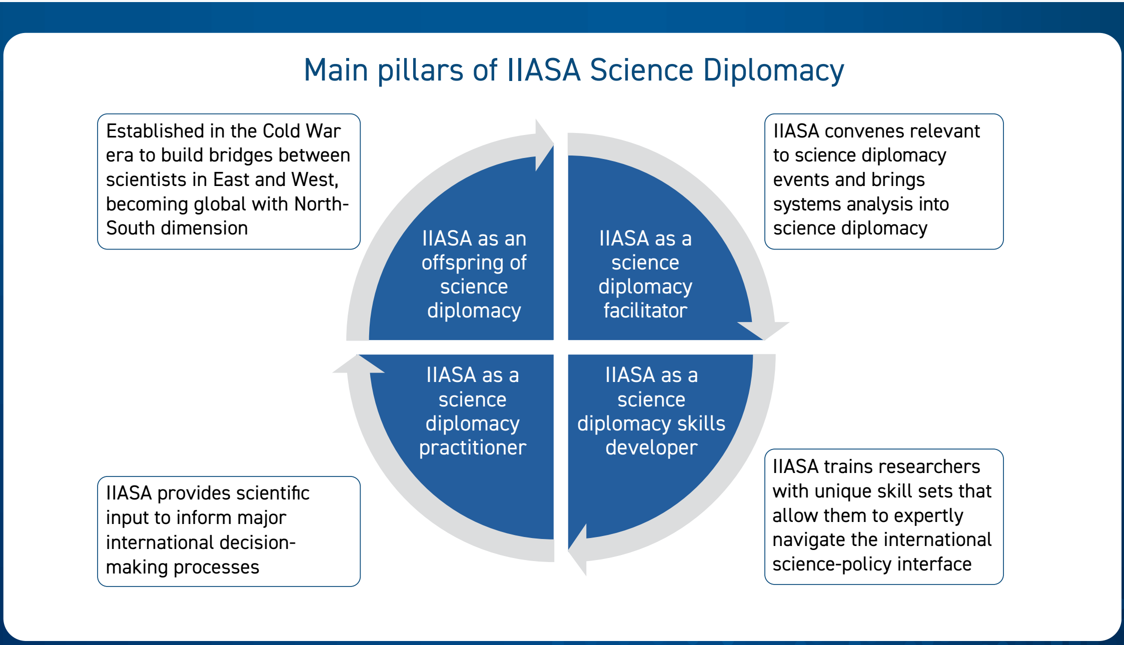
Our messages are grounded in three fundamental ideas. First, taking a compartmentalized "siloed" approach to sustainable development will not achieve the overall goal of sustainable wellbeing—to do this, the application of a systems approach is critical. Second, the ability and the capability of all individuals to exercise agency must be enhanced; while all marginalized people matter, the largest impact can be achieved by empowering women. Third, in addition to individual agency, people's collective ability to exercise joint action and work for global solidarity must be strengthened, and this requires effective global governance with acknowledged legitimacy. With these fundamental concepts in mind, we propose the following three critical messages:

1. Suboptimization is suboptimal: Mainstream a systems-analysis approach into policymaking at all levels.
2. Enhance individual agency: Prioritize women's empowerment through universal female education.
3. Strengthen collective action and governance: Global cooperation and representation for the global commons.

Box 6.1. IIASA and science diplomacy

By Sergey Sizov and Albert van Jaarsveld

Figure 6.1. **Main pillars of IIASA science diplomacy**



Established in the Cold War era to build bridges between scientists in East and West, becoming global with North-South dimension

IIASA convenes relevant to science diplomacy events and brings systems analysis into science diplomacy

IIASA provides scientific input to inform major international decision-making processes

IIASA trains researchers with unique skill sets that allow them to expertly navigate the international science-policy interface

At the time of its creation, IIASA's mission was to promote East–West scientific cooperation and to "build bridges" between the two predominant geopolitical blocs: the United States (USA) and the Soviet Union (USSR). In 1966, amid the Cold War, U.S. President, Lyndon B. Johnson, declared that it was time for scientists of the United States and the Soviet Union to work together on complex shared problems, an idea that was supported by the Prime Minister of the USSR, Alexey Kosygin. After several years of negotiations, the IIASA Charter was signed on 4 October 1972 at the Royal Society in London. The IIASA Charter brought together 12 founding National Member Organizations from Bulgaria, Canada, Czechoslovakia, East Germany, France, Italy, Japan, Poland, United Kingdom, USA, USSR, and West Germany. IIASA can rightfully be called a "child of science diplomacy"—created by policymakers and diplomats to facilitate international research cooperation across geopolitical divides.

Following the end of the Cold War, IIASA transformed itself from an East–West to a global research institute, and currently brings together 21 National and Regional Member Organizations from across the world. Among its current members are major countries of the Global South, including Brazil, China, India, Indonesia, Vietnam, and the sub-Saharan Africa Regional Member Organization which includes 17 African countries (see back cover for a full list of current IIASA National and Regional Member Organizations).

For over 50 years, IIASA has provided independent and policy-relevant research and analyses on challenges of a global or universal nature. It is now considered a world leader in providing systems analytical advice on complex matters that affect the future of humanity. Current geopolitical trends and challenges emphasize the importance of IIASA that acts not only as an independent platform to address emerging global problems through evidence-based systems science, but also as a neutral science diplomacy platform among nations during sensitive negotiations or at times of strife.

In this context, IIASA works constantly to strengthen multilateral science systems and to nurture global scientific partnerships that are indispensable for addressing the UN Sustainable Development Goals, the Paris Agreement, and other global goods. IIASA achieves this by working to soften international tensions, wherever possible and to facilitate collective approaches to resolving shared global problems. IIASA science diplomacy activities are based on the recognition that shared global problems transcend national borders and that all humanity should be able to benefit from the multilateral scientific cooperation activities led by the institute.

Some of the more recent science diplomacy highlights include:

- An open call to the global community from IIASA, the International Science Council, the Sustainable Development Solutions Network, and the International Network for Government Science Advice (INGSA) to strengthen, rather than withdraw from, science diplomacy in the wake of Russia's invasion of Ukraine.[17] The sometimes decades-long efforts by organizations like IIASA to build bridges between nations and communities in order to address matters of common concern are even more important when political relations falter.
- IIASA was at the core of the creation of the Foreign Ministries Science and Technology Advice Network (FMSTAN) and its further development over the past eight years.[18] This included hosting an International Dialogue on Science Diplomacy in 2016, co-organizing the FMSTAN/INGSA meeting in Vienna and Laxenburg in 2019 that helped shape global discussions about using the tool of science diplomacy in foreign affairs, and presenting "Science Diplomacy and Hostile Geopolitics—the Past as a foundation for the Future in 2022."[19]
- IIASA also joined the EU Science Diplomacy Alliance. The institute is ideally positioned to support the objectives of the alliance and contributed to discussions of the New Horizons for Science Diplomacy Concluding Conference in Paris in 2022.[20]
- "IIASA 50th Anniversary Science Diplomacy Event—the Need for International Scientific Cooperation and Multilateralism" brought together over 120 members of the research community, diplomatic corps, and international organizations to discuss the crucial role of continued international scientific cooperation, despite prevailing geopolitical tensions. Discussions resulted in the Vienna Statement on Science Diplomacy, which in the course of a few weeks received endorsements from more than 200 eminent personalities from the academic and policymaking community.[21]

6.1 Suboptimization is suboptimal: Mainstream a systems-analysis approach into policymaking at all levels

Policymaking requires decision-making, sometimes under significant time pressures. Many decisions need to be made under conditions of uncertainty and based on limited information. Often, they are made with specific near-term targets in mind and without integrating broader longer-term considerations. Suboptimization may occur because of a narrow focus on a single sector or issue, or considering an inappropriate spatial or temporal scale, without consideration of broader ramifications. From IIASA's inception in 1972, however, the issue of how to make choices in the near-term that will result in the best long-term outcomes and to address issues systemically has been at the heart of IIASA's approach.

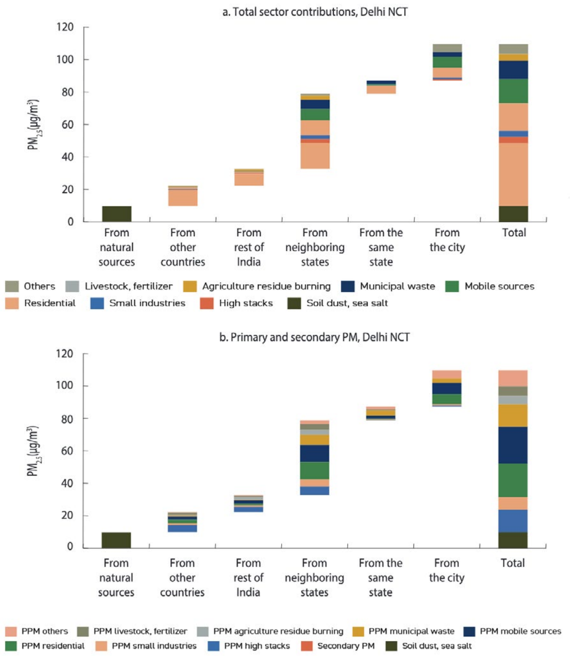
This stance was due in large part to the influence of IIASA's first director Howard Raiffa, one of the founding fathers of the scientific field of decision analysis. For Raiffa,[22] the conventional scientific approach typically articulated a problem into its more specific components, with each being studied in isolation by a team of specialists. IIASA's approach to systems analysis, he believed, should go further: it should in effect, put these slivers back together again so that they could be viewed as parts of an interconnected system. This would show the bigger picture and help understand it. Thus, systems analysis should not only be based on the best disciplinary understanding of the various components but also constitute an inter- and multi-disciplinary effort that considers longer-term outcomes.

In addition, the term "applied" systems analysis indicates that the research should be oriented toward practical problem-solving which requires an analytical approach to be appropriate but also to have the potential to be applied. Thus, while Raiffa's view was that all IIASA research should be guided by this principle of applied systems analysis, he also argued that it should address issues that by nature are either global (affecting all of humanity) or universal (more specific problems that are shared by many different societies).

But why is a policy decision based on systems analysis better than one based on a more conventional sectoral perspective, especially given that, in some cases, optimizing multiple subsystems individually may result in the same system-wide outcome as adopting a comprehensive systems optimization approach? This is because in many cases the narrow sectoral approach may result in unintended negative consequences in other sectors that can exceed the benefits gained from the specific actions taken in isolation and lead to lower levels of overall wellbeing. Or it can result in the wellbeing of current generations being at the expense of that of future generations. These cases are the basis for the saying attributed to Kenneth Boulding—a frequent IIASA visitor in the early days—namely that: "The name of the devil is sub-optimization."[23] The trouble is that we do not know in advance whether the full systemic perspective will lead to a different result from the narrow sectoral one. We discover this only when we make the additional effort to consider the broader systems perspective. That is why a systems perspective cannot be disregarded and needs to be considered in decision-making at all levels.

The world is full of examples of narrow space- or sector-based decisions that have turned out to be suboptimal. Recent IIASA research with the World Bank[24] focuses on air quality in South Asia, which is home to 9 of the world's 10 cities with the worst air pollution, causing an estimated 2 million premature deaths across the region each year (see Figure 6.2). The research highlights how current localized efforts to address air quality in South Asian cities that neglect to assess pollution sources outside a city and that go beyond traditional targets like power plants, large factories and transportation are not likely to be effective. In fact, more than 50% of the air pollution in major cities in South Asia is not local, but travels from across municipal, state and even national boundaries. As a consequence, using a city-by-city approach and focusing on mitigating air pollution generated within cities alone is yielding insufficient results. To achieve greater progress, the focus of policymakers needs to expand into other sectors, particularly small manufacturing, agriculture, residential cooking, and waste management. The research also emphasizes that regional cooperation is important to implement cost-effective joint strategies that leverage the interdependent nature of air quality.

Figure 6.2. **Spatial and sectoral origin of fine particulate matter in ambient air, Delhi National Capital Territory, 2018**



Note. NCT = National Capital Territory; PM = particulate matter; PM2.5 = fine particulate matter; PPM = parts per million; µg/m³ = micrograms per cubic meter. Source: Calculations using GAINS model developed by IIASA, World Bank (2023, p. 3).[24] Reprinted under the Creative Commons Attribution (CC BY 3.0 IGO) License.

IIASA research has demonstrated many more examples of such cases of suboptimization over the years. One relates to the common strategy of trying to improve food security and reduce hunger simply by increasing overall food production, without considering its environmental impacts. Recent work by IIASA's Biodiversity and Natural Resources Program[25] (see more detailed discussion in Chapter 3) has shown that ending hunger by increasing overall food availability would require about 20% more food production and 48 million hectares of additional agricultural land, as well as increasing greenhouse gas emissions by 550 Mt of CO2 equivalents by 2030. If hunger eradication efforts were focused solely on the under-nourished, food demand would increase by only 3% and the associated environmental trade-offs would be largely reduced. Moreover, a combined scenario that targets the under-nourished while also reducing over-consumption, food waste, agricultural, and other environmental impacts would reduce food demand by 9%. This research also shows that taking distribution into account yields very different outcomes and policy priorities.

Other examples can be found in the work of IIASA's World Population Program on the role of education in enhancing adaptive capacity to climate change. Based on the multi-dimensional population models by age, gender, and level of educational attainment (as described in Chapter 2) and their integration into the Shared Socioeconomic Pathways (SSPs) Framework, it was shown that investments in education for all, and in particular for women, are a very effective way of enhancing adaptive capacity and reducing the expected number of fatalities from natural disasters associated with climate change. This is highly relevant in the context of the Green Climate Fund, for which governments have pledged billions of dollars for adaptation action. There is abundant evidence suggesting that empowerment through education, by strengthening resilience at individual and community level, may be more effective in reducing vulnerability than concrete (in both meanings of the word) infrastructure such as sea walls. Despite this, education investments are excluded from the Green Climate Fund.[26] This also illustrates that thinking outside the narrowly viewed adaptation mechanisms may point to win–win strategies that could be completely missed by conventional sectoral suboptimization that looks at specific questions in isolation.

One of the key findings of the Global Energy Assessment (GEA) (see more detailed discussion in Chapter 4) is that a holistic and integrated approach to energy and climate policy which simultaneously addresses multiple objectives for energy sustainability can be better than addressing each objective individually.[27] The GEA pathways clearly illustrate that the simultaneous achievement of energy access, climate change mitigation, energy security, and air pollution control comes at a significantly reduced total energy cost when the multiple economic benefits of each are properly accounted for. In particular, climate mitigation offers a strategic entry point with significant co-benefits for achieving air pollution reductions, enhanced energy security, and other energy sustainability–related goals. When a narrower view of energy challenges with issue-specific policies is pursued, many of these synergies are lost and the total cost of achieving these objectives is higher.

6.2 Enhance individual agency: Prioritize women's empowerment through universal female education

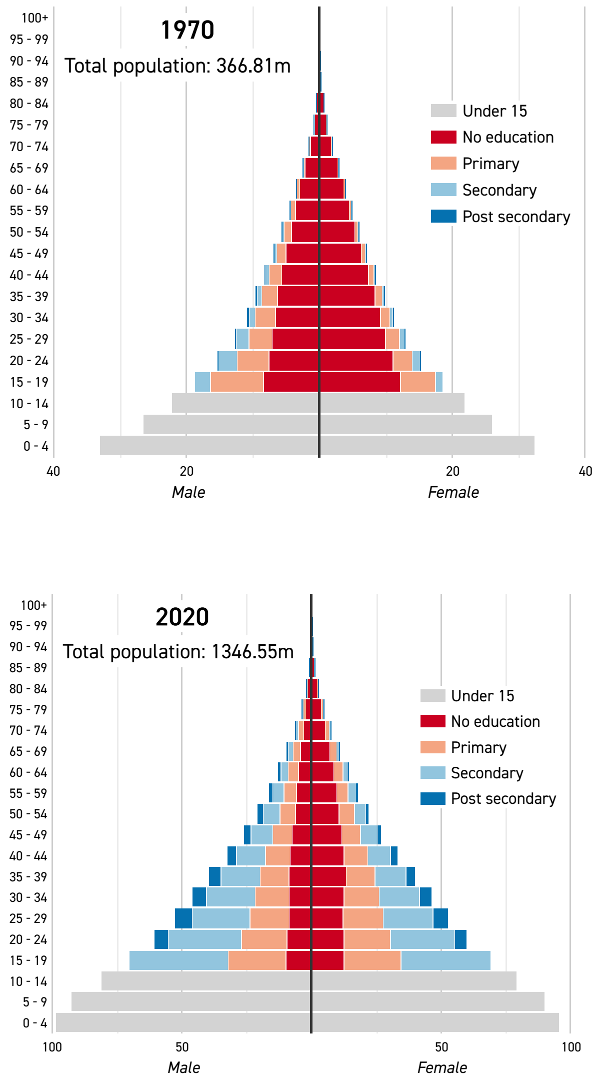
The United Nations, through the Universal Declaration of Human Rights, has enshrined gender equality as a universal human right. Despite the commitment made in SDG 4 and SDG 5, this remains far from being attained; indeed, in both the global North and South, there has been a backlash against gender equality and women's empowerment in recent years. This has been accelerated by the rise in populist authoritarianism, typically associated with "traditional values."

Education is also a universal human right and is the subject of SDG 4 which aims to achieve universal high-quality primary and secondary education. Today, the targets of SDG 4 are also far from being achieved, and education is rarely given the priority it deserves. Policymakers, and development-grant and loan-making organizations need to reprioritize their commitment to achieving this goal and to eliminating gender discrepancies by rolling out high-quality primary and secondary education.

International education data, especially sex-disaggregated data, is notoriously weak, non-comparable, and far from being up to date. This is particularly the case for school enrollment data, a measure of education flows, while information on education stocks of the adult population is more reliable. Data on the highest educational attainment, as registered in censuses and surveys, provides much more reliable information on human capital, and it is such data that is reflected in IIASA's meticulous population reconstructions and projections by age cohort and education level described in Chapter 2. This time series of data on age and gender-specific human capital has provided the basis for many empirical studies on the effects of education on many different aspects of human wellbeing. The data has also helped to understand that while education in general is a key determinant of progress, it is most notably female education that makes the biggest difference. This important insight is also highlighted in the results of the DEMOFeliX model described in Chapter 5.

In many countries, progress in female education has lagged behind that of males. This can clearly be seen from IIASA reconstructions of educational attainment distributions by age and sex for all countries since 1950.[28] In most countries—even in those where gender parity in education was recently achieved or nearly achieved—adult women in age groups above 40 clearly have higher proportions in the low education categories than men. This is due to the great momentum in the changes of educational attainment. In the education pyramids given in Figure 6.3 for Africa, no education is marked in red and primary education in orange. They show that in 1970 among the adult female population (age 25+) 86% had no formal education at all, while this percentage was only 68% for men. Over the past 50 years the overall educational attainment level in Africa has significantly improved, but a clear gender difference remains. In 2020 some 39% of adult women and 25% of the men still had no education. With respect to actual skill levels as measured by skills in literacy adjusted mean years of schooling,[29] this gender gap in education is even more pronounced.

Figure 6.3. **Education pyramids for Africa: 1970, 2020**



Note. Population pyramid in millions. Source: Wittgenstein Centre Data Explorer (2018).[28]

While the educational attainment distributions mainly reflect the legacy of past schooling efforts, the picture presented by current school enrolment, or alternatively by the out-of-school population of school age, also reveals significant gender disparities.[30] Globally, there has been progress on gender parity in education since 2000. Yet, some regional disparities have persisted. These are particularly pronounced for Africa and Asia and, in view of the population weight of those regions, the global ratio of female-to-male primary out-of-school rates is 1.22. The disadvantage of rural girls is much more pronounced than that of urban girls, a classic case of interacting vulnerabilities. Lower-secondary gender disparities are worse than primary school ones, indicative of low parental aspirations for their young daughters. While comprehensive post–COVID-19 data is unavailable, all country-level evidence tends to confirm what was observed in previous global downturns—in times of crisis, particularly in poorer countries, girls are the first to be withdrawn from school for home production activities while boys are kept in school as an investment for the future.

The education of girls is not sufficient for empowerment because so much depends on the social, cultural, and economic context. But, due to its impacts on extra-mural socialization, cognitive skill development, and agency, girls' education is without question necessary. The argument in favor of promoting the education of girls and reducing gender disparities as a policy for accelerating development is overwhelming. The literature on the benefits of girls' education for individual and national economic development is so voluminous that selected citations cannot do it justice.* Aspects that have been studied include impacts on fertility, child marriage, maternal mortality, female genital mutilation, labor force participation and wages, attitudes toward the environment and climate change, participation in political and other public fora, contribution to conflict prevention and peace-making, and others. Education directly affects our abstraction skills and the degree of rationality in our choices as well as the length of the planning horizon for conscious behavior. Girls' education makes girls less risk-averse and more willing to utilize new technologies, enabling them to engage in key growth sectors, such as digitalization and the Green Economy, where they are currently underrepresented, and to use emerging agricultural technologies. Education increases the probability that women will work outside the home, as well as the chance that their participation will be in the organized or formal sector, with enforceable labor

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*For a broad selection from a development advisory group, see British Foreign Policy Group (BFPG, 2020).[31]

contacts and access to public social protection schemes. Educated women are more likely to seek justice in situations of domestic or gender-based violence. Most broadly, female education has the potential to contribute to transformative gender change; that is, to change the power relations that give rise to gender inequality.

IIASA and its associates at the Wittgenstein Centre have made important contributions to understanding the important contribution of gender equality, particularly in education, to global trends. A core finding is that female education and, closely related to it, the speed of fertility decline in Africa, is a major driver of future world population growth—depending on the successful promotion of education for girls, world population scenarios differ by more than one billion people.[32] The stalling of the fertility decline in Africa around the year 2000 can, in turn, be related to the lagged effect of previous disruptions in female education.[33] IIASA researchers have advanced the much-vaunted demographic dividend, namely that growth attributable to fertility decline is, in large part, a dividend due to education, in which girl's education plays the largest role.[34]

As the difficulties of achieving the gender-equality SDGs become more apparent, there is an opportunity, as long as providers of development support, both grants and loans, are interested. The European Union (EU), the world's largest provider of development support, has mandated that 85% of its external financing actions in 2021–2027 should have gender equality and women's empowerment as either a significant or sole objective. The UK government has decided to make girls' education the leading principle of its foreign and development policy, stating, "Education is the root of communities' resilience, the seed of their prosperity, and the linchpin of local and global security. Investments in girls' education, therefore, needs to be approached from a systems level that integrates all aspects of the UK's foreign policy infrastructure to ensure maximum efficiency and impact."[31] In Germany too, there is a strong emphasis on girls' education in the new Feminist Foreign Policy guidelines, launched in March 2023 by German Foreign Minister, Annalena Baerbock, which seek to make gender equality and women's rights central objectives of Germany's external relations.[35] In other countries, similar approaches are being discussed.

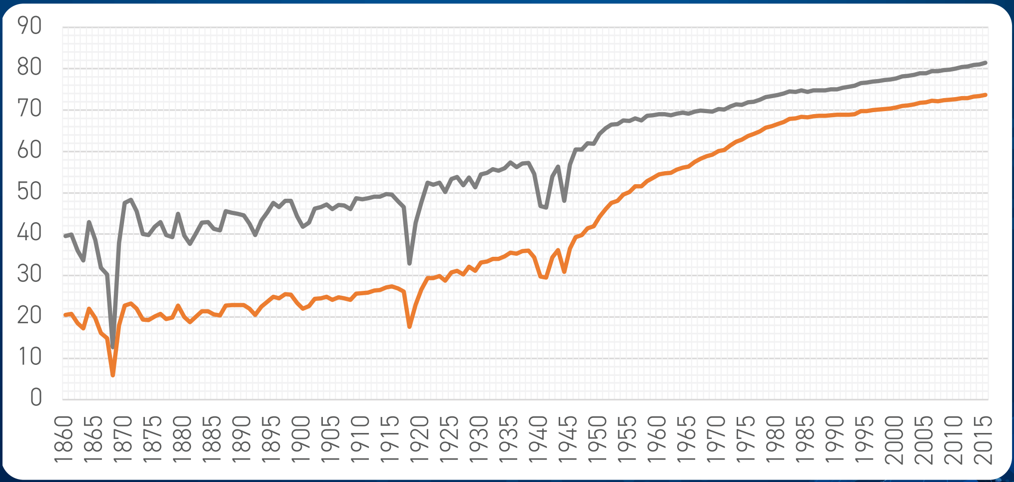
How can IIASA contribute? A recent thematic evaluation of the external actions of the EU in gender in 2018–2022[36] found that while progress has been made, there is still an urgent need for more gender-transformative policies, not only in classic sectoral areas such as education, health, and rural development, but also across the spectrum in areas such as conflict prevention and peace-building, trade, climate change and environment, rule of law, democracy and human rights, and others. Some of the reasons are perennially weak (and sometimes weakening) partner-country political will to implement gender equality as a universal human right; and sometimes tepid (but warming) donor interest. Some have to do with the need to improve partner–country normative frameworks—enforcing anti-discrimination laws, reforming family and property law, and ensuring access to credit—a long-term process. IIASA can contribute by strengthening the research and modeling base to empirically document and simulate—stressing female education—the important linkages between gender equality and sustainability from a systems-analytic perspective. Examples of this are highlighted in Chapter 5 on comprehensive systems modeling. The newly developed DEMOFeliX model, which explicitly incorporates gender differences in education and the effects of education on several other key components of the model, clearly illustrates the paramount importance of female empowerment through education to enhance global wellbeing in the future. IIASA can also deploy its science diplomacy capacity to ensure that these insights are appreciated and followed up on.

Box 6.2. Finland: From one of the poorest corners of Europe to the world's happiest country through education, particularly of women

During most of the 19th century, Finland—previously a province of the Swedish kingdom—was under Russian rule. It was desperately poor and in the late 1860s suffered the last major Malthusian famine in Europe. In 1868 infant mortality peaked at 400/1000 which means that 40% of all children born died before reaching the age of one due to a combination of hunger and disease. Of the total population, 8% died in that year alone because of an almost complete crop failure, no food reserves, and no help from outside.

These incredibly high death rates are well documented because Finland had maintained a very elaborate population register, introduced by the Lutheran church during Swedish times. Life expectancy at birth in 1868 fell to an incredible low of 12.7 years. But even in the years before the famine it had stagnated at below 40 years, less than half of its current level (see Figure 6.4). After this disaster, Lutheran church authorities, together with state officials, concluded that in the absence of any raw materials or other resources—except for some tar from its vast but only slowly growing forests—the only hope for the future lay in developing its human capital. Hence, between 1870 and 1900 the number of elementary school teachers increased by a factor of more than ten[37] and by the beginning of the 20th century, essentially all young women and men were fully literate. Unlike in most other countries, in the early years, female education expanded almost at the same speed as male education and in terms of higher education surpassed that of men by the 1940s. For the past decades Finland has thus been among the world leaders in many indicators of gender equality, including women in responsible political positions; and economically, too, it is considered to be one of the most innovative countries. In the context of wellbeing, for several years in a row the World Happiness Report has listed Finland as number one in the world.

Figure 6.4. **Finland since 1860**



Note: Annual trends in life expectancy at birth (grey line) and an adapted form of the wellbeing indicator Years of Good Life (orange line) as introduced in Chapter 5. Until the 1980s an ever-increasing proportion of total life was classified as good under this definition. Since then, the two indicators move essentially in parallel due to population aging and associated old-age disabilities. Source: Reiter and Lutz (2019).[38] Adapted under the terms of the Creative Commons Attribution 4.0 International License.

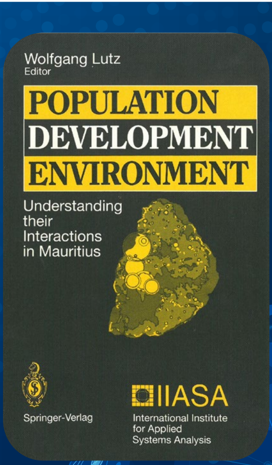
Box 6.3. Mauritius: From a textbook case of the poverty trap to the most prosperous and happiest country in the African region, with education and female empowerment having played a decisive role

In 1968 at the time of independence after centuries of colonial rule by the Dutch (1598–1710), the French (1715–1810) and the British (1810–1968), the island of Mauritius was characterized by high unemployment and widespread poverty, with an economy primarily dependent on sugar cane and its volatile world market price. It had very high population density due to its limited land surface and a history of high immigration—most of its indentured laborers were brought from India—together with birth rates of more than six children per woman. Mauritius was subsequently used as a textbook example for a country trapped in the vicious circle of high population growth, poverty, and environmental degradation.[39]

The democratic government of the newly independent state managed to escape from this “trap” with a set of highly effective long-term policies ranging from a strictly voluntary family planning program to massive investments in human capital. Secondary school enrollment of girls more than doubled within a decade from 23% in 1970 to 50% in 1980. At the same time the Total Fertility Rate (mean number of children per woman) declined from over 6.0 children in 1962 to 2.8 in 1980 and 2.0 in 1986, one of the world’s most rapid fertility declines. Today, fertility is similar to European levels of 1.4, while the average of the sub-Saharan African region is still around 4.5.

In terms of economic policies resulting in rapid poverty reduction, Mauritius also seemed to benefit from its ethnically diverse population that maintained connections with the rest of the world and fostered trading relations, promoted a balanced economy away from reliance on sugar; this led to participatory political institutions that have been able to sustain democracy on the island.[40] With an export-oriented economic policy, the increasingly skilled women who had fewer children to look after found jobs in the textile industry, resulting in the first phase of economic growth that brought the county out of extreme poverty. A second economic push was associated with the rapid growth of the tourist industry, with Mauritius aiming explicitly at high-end tourism which was only possible with a well-trained hospitality industry labor force. In recent years, Mauritius has rapidly expanded its skills-based IT services and development industry—with women playing a key role—making it not only the IT and banking hub of the region but the most economically advanced country in the entire African region, even surpassing South Africa. It is remarkable that, ethnically and religiously, Mauritius is also one of the most diverse countries in the world. Evidently, high levels of education and female empowerment have been conducive to the development of balanced and elaborate institutions for a peaceful and productive co-existence of the Hindu, Muslim, Chinese, and European religious and ethnic groups in the same communities. And in the World Happiness Report, Mauritius now ranks number one in the Africa region.

Figure 6.5. ***Population Development Environment***[39]



Wolfgang Lutz
Editor
POPULATION
DEVELOPMENT
ENVIRONMENT
Understanding their Interactions in Mauritius
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6.3 Strengthen collective action and governance: Global cooperation and representation for the global commons

Climate change, biodiversity losses, pollution, and over-extraction of the world's natural resources are just a few of the many problems related to the management of the global commons that have been discussed in this report. These challenges along with many social issues such as persistent poverty and intersecting and growing inequalities are all urgent in the sense that they require immediate action at the global scale to avoid irreparable harm to current and future generations as well as to humanity's post–Cold War ambitions. The interconnected and transboundary nature of many of these issues means that they require unprecedented levels of global collaboration and cooperation that go beyond the current world order.

Today, nation states are still the principal entities that govern individual societies and their interactions with international communities on matters that transcend national boundaries. The ability of a state to govern effectively depends in large part on state authority, capacity, and legitimacy.[41] Challenges to govern effectively, however, exist to a greater or lesser extent across the globe. This means further efforts are needed in terms of governance reform and to strengthen national, international and global institutions so that they become more transparent, accountable, credible, adaptive, and inclusive. The intention to seek peace, justice, and strong institutions is also enshrined in SDG 16 and its targets. Like all public goods, the global commons are also at risk of being undermanaged. Governing global collective problems calls for deeper cooperation and high-quality institutions to support more ambitious policies, to lend credence to these, and to effectively implement and evaluate policies and oversee these once they have been decided. This is where common interest requires urgent collective global action.

Growing frustration with existing ways of shared management of the global commons and transboundary issues have given rise to calls for innovations in such a way as to enhance collective agency and action and to transform global governance regimes. Several different perspectives have been offered. *The World in 2050* report—coordinated and led by IIASA—concluded that the world needs "adaptive polycentric multi-sector, multi-level, multi-scale and multi-actor governance approaches."[41] The report also highlighted four main criteria that are important for transformative governance including (1) horizontal coordination across policy sectors; (2) vertical coordination across levels of state and government; (3) multi-stakeholder engagement; and (4) high-level political leadership.

While the need for reform of the global governance landscape is recognized and agreed upon by many, the form a new regime should take is still being debated. Some have argued that current processes involving decisions being made through consensus by national governments are inherently too conservative and slow, given the urgent challenges we face today.[42] They also argue that, instead, new alliances between state and non-state actors (including scientists) are needed that are enabled to test new and bold solutions for faster decarbonization—in other words, concerted and ambitious action needs to be delivered by a select coalition of the willing (see Box 6.4). Such a coalition even formed the initial basis of the United Nations when delegates from 50 nations convened in San Francisco on 26 June 1945 to sign the UN Charter. Others have raised fundamental concerns regarding the current global governance regime and have argued for a completely new governance architecture (see Box 6.5).

Despite differences in views about how to reform the current global governance regime, recognition of the need to bridge the knowledge–action gap through transformed science–policy and science–society interactions is common among the divergent views.[41,43,44] It is also important to highlight that any new global governance system is likely to have important implications for efforts to transform women's empowerment and mainstream systems approaches into policymaking. Thus, while the three critical policy messages presented in this chapter are distinct and each of them is important, together they form a broader call for structural change. Such change would need to recognize existing inequities, and existing and past injustices, and re-evaluate the current systems of people–nature relationships, broader societal organization, and global order with the ultimate goal of achieving sustainable wellbeing for all.

Box 6.4. Improving global governance: The three confusions

By David G. Victor

The author had three stints in residence at IIASA—first as a summer student in 1989 just before the Berlin wall tumbled, then in the early 1990s as a leader in the Implementation and Effectiveness of International Environmental Commitments (IEC) project, and finally as a research associate with the energy and technology projects in the late 1990s. He witnessed IIASA making a big pivot—away from a central focus on cold war bridging and toward global issues. His IIASA work on global governance (IEC) and a subsequent career working on the same issues has made him optimistic and pessimistic about the future.[45] Optimism is based on the fact that the analyst community has learned a lot about "what works," and governments, too, are often adopting those more effective strategies. Pessimism comes from the inability to shake off the old, ineffective models more fully for global governance.

IIASA-based research has shown that three confusions should be avoided:

Don't confuse grand goals with strategies.

Ever since the 1992 Earth Summit in Rio—indeed, long before—it has been clear that many issues are inescapably global. The list includes biodiversity loss, climate change, protection of the oceans, stewardship of antibiotics, and many others.[46] The complexity inherent in such global problems is a dream world for ecologists who emphasize the interconnectedness of life. For the solvers of global problems, however, it can be a nightmare. Where do you begin to craft solutions? If a problem is truly global, does it have any scope conditions that define membership, content, and strategies for international agreements?

The first confusion in global governance comes from the lack of clear answers to those questions. The default position has been that when a problem is identified as "global" the solutions must be global as well. And when global problems are taken up by the UN system, that default position is hard to shake because the norms of universality are so powerful.

That default position has, for the most part, been a recipe for disaster. The runup to the Rio Summit saw that disaster play out with the inability to reach any meaningful agreement on forests. On climate, the United Nations Framework Convention for Climate Change (UNFCCC) was, at best, a holding pattern. The Convention on Biological Diversity has generated a lot of meetings and exhortations, but it isn't clear it has done much to help biodiversity.

Alternative approaches emphasize the need to get started in small groups of highly motivated actors who can begin to cooperate. Through cooperation they create new interests—that is, interest groups that grow to favor more cooperation—and through that cooperation they can deepen and expand. Many analysts call this a "club" approach to cooperation, and it has been debated extensively in the area of climate change in particular.[47,48] In the IIASA IEC project, this topic was looked at through the lens of participation—how do strategies that actively shape membership in early agreements affect the prospects for later, deeper cooperation? [49] The clear lesson from history: starting big and broad with conflicting interests generates pablum as content. Starting smaller often works much better. When the UK government hosted COP26 in Glasgow it adopted this strategy with great effect—it built clubs of countries and firms that were highly motivated to find solutions. Membership in each club varied by sector.[42]

A key policy issue concerns the strength of the mechanisms used to delineate and enforce membership in the club. For this, it is helpful to distinguish between "strong" and "weak" clubs. Strong clubs often envision linking club membership in good standing to benefits in the form of trade and investment. That was done in the accords that protect the ozone layer and is one reason why they were effective. There have been ideas advanced to create strong climate clubs with severe trade penalties for noncompliance.[47] There are ideas, as well, that envision starting with weaker club arrangements—with subsidies and modest linking to trade as governments and firms learn what is feasible.[48,50]

In a world where international economic institutions, such as the World Trade Organization (WTO), are already under threat there is a danger that creating environmental clubs of inordinate strength will cause a lot of additional harm to economic institutions. Thus, the author's own research has been in favor of weaker clubs—not because strong mechanisms are ineffective, but because their collateral damage could be high.

Don't confuse strategic incentives

A second confusion arises when analysts and policymakers forget to look at incentives. This happens all the time, sadly. In global climate talks Western analysts and governments assume that all countries join global climate treaties because they are centrally concerned with climate change. Even when governments say that climate change is their concern, quite often other matters are understandably higher in priority—like economic development and preferential trade rules. Thus "climate negotiations" aren't really diplomacy about regulating emissions as much as diplomacy about all the other things that are linked to regulation of emissions. And when preferences are expansive, that list of linked topics is huge.

It is important to pay close attention to incentives—including the incentives to cooperate. Framing global governance problems in broad, transformative terms also leads, often, to global prisoners' dilemma framing for which solutions are nearly impossible to craft. (When enforcement mechanisms are weak, then solving such problems is additionally difficult. Outside a few arms control treaties, there aren't really any effective global enforcement mechanisms that can be tapped reliably.)

Problems can, however, be reframed—in the words of one recent article criticizing prisoners' dilemma framing, the analyst community has assumed we are "prisoners of the wrong dilemma." Indeed, some of the big success stories in global cooperation have involved transforming problems from such a framing to different kinds of incentive structures that are more about assurance and delivery of conditional benefits—all much more favorable to forging and sustaining cooperation.

Don't confuse compliance with efficacy

In the early 1990s a love affair between international relations and international law was in full swing. Both agreed to collaborate to address what, at the time, was thought to be a major crisis in global governance: compliance. What could be done to boost levels of compliance? After several empirical efforts to measure compliance had run their course, also at IIASA—it became clear that compliance was actually very good. Abe Chayes and others led excellent scholarship to help explain why governments took compliance seriously.[51] But a larger issue also emerged: compliance was high because governments designed treaties for easy compliance. Indeed, that was the real crisis: compliance was too high because efforts were too modest. Goalkeeper and striker were in cahoots—goals were adjusted to make sure the striker always scored.

At IIASA this problem was approached, in part, by looking at legal form. Binding treaties were particularly likely to generate high compliance because they were taken most seriously—and thus most likely to find goals aligned with what was achievable, not what was needed. Indeed, in some areas binding and non-binding agreements were operating in parallel, and most of the "effect" of cooperation came from the nonbinding processes.[49,52] A solution was to make much greater use of nonbinding agreements—to set goals that went beyond what governments knew how to implement.[53,54] That insight suggested that efficacy—that is, solving environmental problems—might come when compliance was perennially low because goals were always just beyond reach, but the process of setting goals motivated governments and firms for more action.

Box 6.5. Might a global parliament help improve governance of the global commons?*

Deliberations of IIASA's Transformations within Reach (TwR) initiative

A global governance system based on individual nation states working for their own self-interest may not be an optimal setting for successfully prioritizing the protection of the global commons for the future of all of humanity. Going beyond the current system of reliance on voluntary collaboration among sovereign nation states to address global issues, is a proposal for the establishment of a cosmopolitan institution representing all members of the world population in a credible manner, and thus a body that can claim with legitimacy "we the people" and not just "we the governments".

The most comprehensive background information on this topic of a "world parliament," including the history of the idea and many of the arguments in favor of such an initiative, as well as the unsuccessful attempts to implement it over the past century, is provided in a book by Leinen and Bummel[55] on which this section also draws.

This concept has a millennia-long tradition in different cultures around the world and over the years has received explicit and strong endorsements from leading intellectuals and statesmen including: Albert Einstein, Albert Camus, Amartya Sen, Indira Gandhi, Nelson Mandela, and Jacques Delors. Despite an abundance of specific proposals, this idea has still not been implemented.

What is different today that would make the implementation of this idea more feasible? There are two important developments that distinguish the present-day situation from that of past decades:

- The growing number of alarms raised about climate change, biodiversity loss, food–water and energy security, and other environmental problems have such a solid scientific base and received so much public attention that they can no longer be ignored by any responsible state leadership. The acute awareness of impending global catastrophes that threaten humanity's future adds a powerful new incentive and a

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*This section was informed also by a consultation with the Community of Science and Practice of the Transformations within Reach (TwR) project (https://iiasa.ac.at/projects/TwR).

degree of urgency to the arguments of the past which largely revolved around peace and security concerns and were founded on philosophical and value-based considerations. These existential threats to our global commons urgently require the voice of the people, by the people, for the people to be heard.

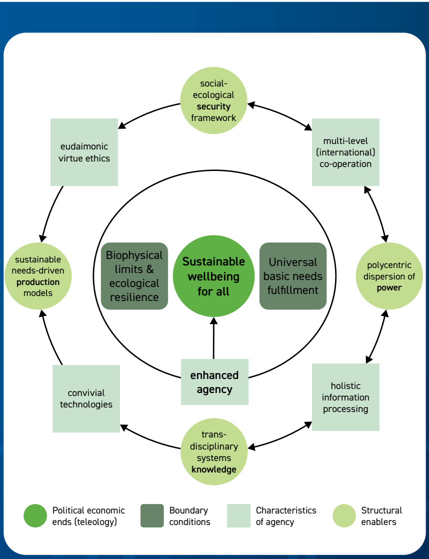
- In the European Parliament we now have a convincing living example of the functioning of a supra-national parliament. If states like Germany and France who over the centuries have fought intense wars with each other now cooperate peacefully both in the context of the European Council (we the governments) and the European Parliament (we the people), why should this approach not be possible at the global level as well? The evolution of the European Parliament also demonstrates another important lesson: even if you initially start with a more modest parliamentary assembly of members sent by national parliaments whose votes have only symbolic power, over time this could evolve into true legislative power.

Given this new reality, one pragmatic, legally and politically feasible proposal suggests starting with the establishment of a United Nations Parliamentary Assembly.[55,56] This proposal, spearheaded by the Harvard law professor Louis B. Sohn in 1949 foresees the establishment of such an assembly simply through a resolution of the UN General Assembly under Article 22 of the UN Charter. This allows for the establishment of such subsidiary organs as are deemed necessary for the performance of its functions. The allocation of seats in such an assembly could then be in proportion to a country's population size.

Several open questions remain, as to how such a system could be realized, might work, and be truly representative and inclusive. Specifically, there are concerns about how such a system could be legitimized, avoid corruption and capture, and how enforcement and monitoring mechanisms in such a system might best function.

Over the 20th century, progress in the development of global governance always followed major catastrophes. The League of Nations was formed right after World War I and the UN right after World War II. It is to be hoped that the next decisive step in improving global governance will not have to wait for another major catastrophe, which this time may also be linked to consequential and irreversible environmental change. The question remains: Does humanity have the foresight to extend global governance beyond the current system of national self-interest to one that is in the common interest?

Figure 6.6. **Transformations within Reach (TwR-II) framework for societal transformations**



Note. Launched in early 2020 jointly by IIASA and the International Science Council and under the patronage of H.E. Ban Ki-moon, the TwR initiative aims to glean lessons from the COVID-19 crisis for the future of society. Since then, over 200 experts from various disciplines and world regions have provided recommendations on what should be done to move toward a more sustainable world. The figure shows a framework for societal transformations that emerged from extensive literature review and discussions with experts. As illustrated in the figure, greater international co-operation is essential to beget a virtuous cycle for societal transformation toward sustainability, and the world parliament could be a powerful step in this direction.[57] Figure courtesy: IIASA-TwR-II 2022.

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Chapter 4

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Chapter 6

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IIASA HIGHLIGHTS
50 YEARS OF ACHIEVEMENTS

1972 | 1974 | 1975 | 1977 | 1978 | 1980 | 1981 | 1982 | 1983

1972

FOUNDING OF IIASA

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

EXPANDING THE STUDY OF ADVANCED SYSTEMS SCIENCE

George Dantzig, winner of the US National Medal of Science, and Nobel Prize laureates Tjalling Koopmans (USA) and Leonid Kantorovich (USSR) expand on an IIASA study of advanced systems science and methodology.

1975

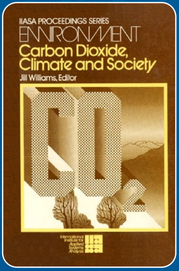
THE FIRST ECONOMIC MODEL OF GLOBAL WARMING

Nobel Prize winner William Nordhaus' career is given a jump start at IIASA when he publishes the first economic model of global warming.

1977

THE FIRST YOUNG SCIENTISTS SUMMER PROGRAMME (YSSP)

The first YSSP is a huge success, and since 1977 IIASA has attracted over 2100 talented young scientists to spend a summer working with scholars from other nations and disciplines.



IIASA PROCEEDINGS SERIES
ENVIRONMENT
Carbon Dioxide, Climate and Society
Jill Williams, Editor
International Institute for Applied Systems Analysis

1978

SOLUTIONS TO TACKLE CLIMATE CHANGE

IIASA scientists warn the world about the dangers of climate change and suggest pioneering solutions such as capturing and storing carbon.

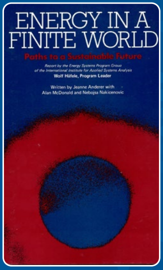
ADAPTIVE ECOSYSTEM POLICY AND MANAGEMENT

A new research field, Adaptive Ecosystem Policy and Management, is founded at IIASA and has implications for forest management policy throughout North America and Scandinavia.

1980

PROJECTIONS OF POPULATION AGING IN DEVELOPED COUNTRIES

US demographer James Vaupel and Soviet mathematician Anatoli Yashin develop more reliable projections of population aging in developed countries.



ENERGY IN A FINITE WORLD
Paths to a Sustainable Future
Report by the Energy Systems Program Group of the International Institute for Applied Systems Analysis
Wolf Häfele, Program Leader
Written by Jeanne Anderer with Alan McDonald and Nebojsa Nakicenovic

1981

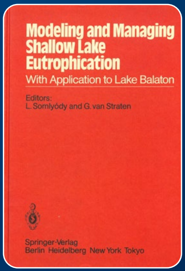
ASSESSING GLOBAL ENERGY ISSUES

IIASA publishes the first comprehensive, truly global assessments of energy issues, resulting in the internationally acclaimed report, *Energy in a Finite World*.

1982

INFLUENCING WATER POLICY WORLDWIDE

The findings of a comprehensive IIASA study on eutrophication and management of Lake Balaton influence water policy in Italy, Japan, the USA, and the USSR.



Modeling and Managing Shallow Lake Eutrophication
With Application to Lake Balaton
Editors:
L. Somlyódy and G. van Straten
Springer-Verlag
Berlin Heidelberg New York Tokyo

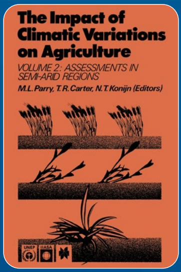
1983

A MODERN APPROACH TO INCREASING RETURNS

Groundbreaking IIASA research pioneers the modern approach to increasing returns showing how powerful firms can exploit the nature of high-tech markets to the disadvantage of opponents who offer better products.

CONNECTING EAST AND WEST

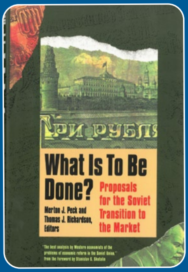
Researchers at IIASA establish a computer network reaching beyond the Iron Curtain—10 years before the Internet.



1988

RESPONDING TO GLOBAL FOOD ISSUES

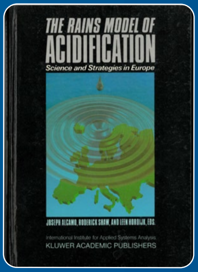
IIASA creates a computer model: Basic Linked System, that becomes a practical tool for determining the effectiveness of policies to eliminate hunger and the impacts of agricultural trade liberalization.



1991

PROPOSALS FOR THE SOVIET TRANSITION TO THE MARKET

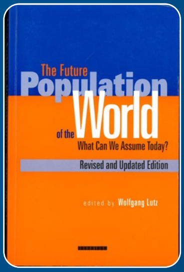
IIASA brings together leading economists from Eastern and Western Europe, Japan, the USA, and the USSR to identify economic reforms to help the Soviet Union overcome its economic crisis and make the transition into a market economy.



1994

MODELING EUROPE'S ACID RAIN PROBLEM

The IIASA Regional Acidification Information and Simulation (RAINS) scientific model underpins the Geneva Convention on Transboundary Air Pollution to reduce damaging emissions of sulfur dioxide.



1996

PROBABILISTIC POPULATION SCENARIOS

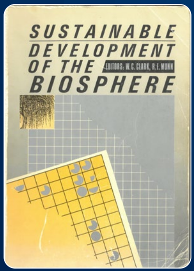
The second edition of the IIASA book *The Future Population of the World: What Can We Assume Today?* includes the first-ever probabilistic population scenarios and new findings on population aging.

1986 | 1988 | 1989 | 1991 | 1992 | 1994 | 1995 | 1996 | 1998

1986

INTRODUCING SUSTAINABLE DEVELOPMENT

IIASA scholars publish *Sustainable Development of the Biosphere*, which is quickly accepted by the science community as the core scientific text on sustainable development.



1989

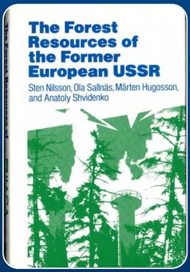
TECHNICAL SUPPORT FOR THE GENEVA CONVENTION ON TRANSBOUNDARY AIR POLLUTION

An IIASA model analyzing Europe's acid rain problem is adopted by all 28 countries of the Geneva Convention on Transboundary Air Pollution.

1992

ASSESSING FUTURE FOREST RESOURCES

The first consistent continent-wide assessment of forest resources in Europe and the European regions of the former Soviet Union conducted at IIASA reveals alarming consequences of air pollution for European forests.



1995

EXTENDING THE RAINS MODEL TO ASIA

The IIASA 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.

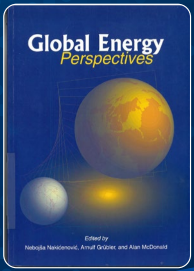
IIASA SCHOLARS CHOSEN FOR LEADING ROLES IN THE IPCC

Five IIASA scholars are chosen to be lead authors of the Second Assessment Report of the IPCC. Since then, over 50 IIASA scientists have played leading roles in the IPCC Assessment Reports.

1998

FUTURE SCENARIOS OF ENERGY PRODUCTION

The World Energy Council partners with IIASA in a unique study on *Global Energy Perspectives*, which analyzes how current and near-term energy decisions will have long-lasting implications throughout the 21st century.



2000 2001 2002 2004 2005 2007 2008 2011 2012 20

2000

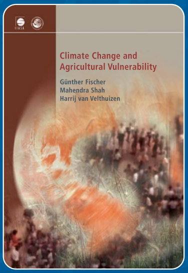
SPECIAL REPORT ON EMISSIONS SCENARIOS

IIASA scientists and models play a leading role in preparing the most comprehensive scenarios yet of greenhouse gas emissions for the 21st century.

2001

FORECASTING THE END OF WORLD POPULATION GROWTH

Demographers at IIASA are first to forecast that the world population will peak in the 21st century and then begin to decline.



2002

THE IMPACTS OF CLIMATE CHANGE ON AGRICULTURE

The UN commissions IIASA scientists to analyze the likely impacts of climate change on agriculture to 2080.

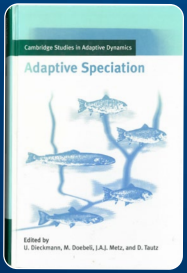
STUDYING RUSSIAN LAND RESOURCES

IIASA scientists complete the most comprehensive study of Russian forests and land resources ever undertaken.

2004

DOCUMENTING EVOLUTIONARY CHANGES IN FISH STOCKS

IIASA scientists reveal that undesirable genetic changes are taking place in fish stocks due to commercial exploitation.



2005

REFOCUSING DISASTER AID

An IIASA study identifies several innovative approaches to free vulnerable countries from dependence on unpredictable post-disaster assistance.

2007

IIASA SCIENTISTS RECEIVE A SHARED NOBEL PEACE PRIZE

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".

2008

ASSESSING THE TRENDS IN AGING

In one of the most cited papers on global aging, IIASA researchers show that the global speed of aging is likely to peak between 2020 and 2030, and then decelerate.

CUTTING GREENHOUSE GASES IN EUROPE

IIASA analyses provide quantitative information to the European Commission for the proposal and subsequent negotiations on the EU Climate and Energy Package.

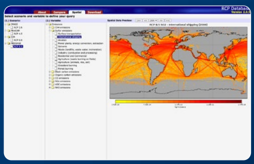
THE IMPACT OF BIOFUELS ON GLOBAL WARMING

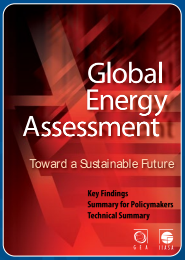
Research from IIASA and partners warns that the production of some commonly used biofuels can contribute significantly to global warming.

2011

INPUT FOR PROSPECTIVE CLIMATE MODEL EXPERIMENTS

The Representative Concentration Pathways database is co-developed and hosted by IIASA, equipping the climate change research community with common greenhouse gas emissions data.





2012

A GLOBAL ENERGY ASSESSMENT

The first ever fully integrated *Global Energy Assessment* provides the scientific basis and key objectives for the UN Sustainable Development Goal #7 on ensuring access to sustainable energy for all.

14 MEASURES TO REDUCE GLOBAL WARMING

IIASA and partners identify 14 measures to reduce short lived climate forcers such as methane and ozone, providing scientific evidence for the Climate and Clean Air Coalition.

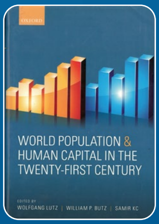
2013

STRENGTHENING RESILIENCE TO FLOOD RISK

IIASA partners with the Zurich Flood Resilience Alliance to apply systemic risks research to help two million people around the globe become more resilient against flooding.

LAUNCHING GEO WIKI

A revamped Geo-Wiki is launched by IIASA and partners to harness the power of citizen science to collect and verify land cover data, thereby dramatically improving the quality of the data.



OXFORD

WORLD POPULATION & HUMAN CAPITAL IN THE TWENTY-FIRST CENTURY

EDITED BY
WOLFGANG LUTZ | WILLIAM P. BUTZ | SAMIR KC

2014

WORLD POPULATION IN THE 21ST CENTURY

IIASA publishes the first population projections that include the level of educational attainment for all countries of the world.

PROMOTING EURASIAN ECONOMIC INTEGRATION

High-level officials and experts from across Europe, the Eurasian Economic Union, and Asia are brought together by IIASA to explore the challenges and opportunities of establishing closer economic relations and the creation of a common economic space.

2016

INSIGHTS ABOUT INDIRECT CARBON AND LAND IMPACTS FROM BIOFUELS

Research by IIASA and partners provides inputs to the revisions of the EU Renewable Energy Directive including the introduction of biofuels sustainability criteria for all biofuels produced or consumed in the EU.

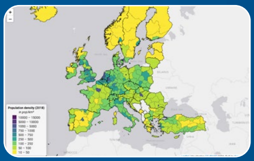
2018

INFLUENCING ZAMBEZI RIVER STRATEGIC PLANNING

The Zambezi River Basin Commission develops a strategic plan for water, energy, and food management based on findings from an IIASA-led study.

SPECIAL REPORT ON GLOBAL WARMING

The IPCC publishes its Special Report on Global Warming of 1.5°C. The report involved 224 contributing authors from 40 countries of which 12 were from IIASA.



2020

THE IIASA COVID-19 TRACKER

IIASA researchers develop a tracker that visualizes regional data on daily COVID-19 cases for 26 European countries. It highlights key demographic and socioeconomic information to help inform decisions by health professionals, governments, and policymakers to address the crisis.

2022

THE VIENNA STATEMENT ON SCIENCE DIPLOMACY

IIASA releases the Vienna Statement on Science Diplomacy, emphasizing the benefits that science diplomacy can bring to addressing the global challenges of our time.

A MODEL FOR MACROECONOMIC FORECASTING

An IIASA-led research team develops the first agent-based model that is competitive with traditional models for macroeconomic forecasting, combining data from various sources to create a detailed picture of the economy.

13 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022

2015

CONTRIBUTING TO THE PARIS AGREEMENT

IIASA science contributed to talks leading up to the Paris Agreement, providing the only study to show that it was technologically feasible to limit global warming to 1.5°C above pre-industrial levels.

SDGS FORMALLY ADOPTED

The UN Sustainable Development Goals are formally adopted, with IIASA science underpinning goals on tackling climate change and ensuring access to sustainable energy for all.

2017

PRIORITIZING INVESTMENTS IN EDUCATION

Informed by a decade of IIASA demographic research on the importance of investments in education for development, the German Federal Ministry for Development allocates 25% of its entire funding for education.

2019

A NEW VISION OF POPULATION AGING

IIASA demographers introduce a completely new way of measuring aging defined not only by chronological age but also by other factors such as life expectancy.

STRENGTHENING AIR QUALITY IN CHINA

The Chinese Government officially adopts the IIASA Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model.

TOWARD A LOW-CARBON ECONOMY IN INDONESIA

IIASA contributes to a groundbreaking report showing how Indonesia could gain tremendous economic benefits by transitioning to a low-carbon economy.

2021

INFORMING BIODIVERSITY POLICY NEGOTIATIONS

IIASA research is taken up in the development of the post-2020 Biodiversity Framework of the Convention on Biological Diversity.

PATHWAYS TO A POST-COVID WORLD

IIASA partners with the International Science Council to bring together hundreds of experts to use systems thinking to identify how best to rebuild a world that is more resilient, sustainable, and just.

International Science Council

Transformations within reach:
Pathways to a sustainable and resilient world

STRENGTHENING SCIENCE SYSTEMS

2022

CREATING OPPORTUNITIES FOR SYNERGIES

IIASA hosts the Forum on Scenarios for Climate and Societal Futures, bringing together over 500 researchers who are using or developing scenarios for use in climate change and sustainability analysis.

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This report chronicles the half-century-long history of the International Institute for Applied Systems Analysis (IIASA), established in 1972 in Laxenburg, Austria, to address common social, economic, and environmental challenges at a time when the world was politically dominated by the Cold War.

The report reveals IIASA's transition from its original raison d'être as a cooperative scientific venture between East and West to its position today as a global institute engaged in exploring solutions to some of the world's most intractable problems—the interconnected problems of population, climate change, biodiversity loss, land, energy, and water use, among others.

It provides a concise overview of IIASA's key contributions to science over the last 50 years and of the advances it has made not only in analyzing existing and emerging trends but also in developing enhanced scientific tools to address them. The report also shows how IIASA is currently working with distinguished partners worldwide to establish the scientific basis for a successful transition to sustainable development.

At this critical mid-term review point of the 2030 Agenda for Sustainable Development, the report focuses on the big picture and clarifies why, after years of scientific endeavor, the ultimate goal of this difficult global mandate should be sustainable wellbeing for all.

The report is in six parts that summarize past and current IIASA research highlights and points toward future challenges and solutions: i) Systems analysis for a challenged world; ii) Population and human capital; iii) Food security, ecosystems, and biodiversity; iv) Energy, technology, and climate change; v) Global systems analysis for understanding the drivers of sustainable wellbeing; and vi) Moving into the future: Three critical policy messages.

The three critical policy messages, necessary to trigger discussions about a post-2030 Agenda for Sustainable Development are: (1) Suboptimization is suboptimal: Mainstream a systems-analysis approach into policymaking at all levels. (2) Enhance individual agency: Prioritize women's empowerment through universal female education; and (3) Strengthen collective action and governance: Global cooperation and representation for the global commons.

International Institute for Applied Systems Analysis (IIASA)
Schlossplatz 1 | A-2361 Laxenburg, Austria

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