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

IIASA SELF-ASSESSMENT REPORT 2021-2024

31 May 2024

Preface

This self-assessment report (SAR) provides a comprehensive summary of IIASA activities and achievements over the past 3.5 years.

Following a major restructuring of IIASA research efforts into five scientific programs (i.e. Advancing Systems Analysis (ASA), Biodiversity and Natural Resources (BNR), Energy, Climate and Environment (ECE), Economic Frontiers (EF), Population and Just Societies (POPJUS)), and a separate Program for Strategic Initiatives (SI), in January 2021, the institute entered a new phase as guided by its Four-year Research Plan 2021-2024 as well as its Ten-year Strategic Plan 2021-2030.

With the current research-plan period drawing to an end, the IIASA Council Executive Committee has commissioned an independent external scientific review by eminent international scholars for a critical appraisal of the work done. Based on this assessment, we also ask the review committee for valuable guidance regarding the development of the next IIASA Research Plan 2026-2029. The production of a self-assessment report (SAR) by the end of May 2024 was identified and executed as the first step in this overall process.

We are confident that this SAR demonstrates how IIASA research activities significantly expanded over the past years, both in terms of volume and in terms of quality of output, which included publications in the highest-level journals and significant international policy impact. This all happened despite of the serious challenges posed by the COVID-19 pandemic and the escalation of conflicts involving several IIASA member countries.

As a section on benchmarking in the first chapter of this report illustrates, IIASA also fares very well in comparison to other international research institutes in the field of global change and leading research institutes in the Austrian context. As can be seen in the financial section of the report, the advances of the scientific work at IIASA were also driven by a strong expansion of external funding, while at the same time the contributions from member organizations were stagnant. This issue will be a priority focus for the IIASA executive in the near future.

Due to the enormous volume of the materials to be reviewed, the SAR comes in form of six pieces: this summary document for the whole institute (without detailed lists of references, publications or individual projects) plus five program documents that do include the full set of lists and tables for the respective research programs.

We trust that the evaluators find this information helpful and that we manage to convey some of the collective excitement of IIASA staff in studying the biggest challenges that humanity faces in the 21st century. We do so by applying and advancing genuine systems thinking. At the same time, we try to generate policy impact based on our scientific evidence. In a way, IIASA mission has just started.

Hans Joachim Schellnhuber
Director General

Wolfgang Lutz
Interim Deputy Director General for Science

Contents

1. Institute-wide activities including statistics and benchmarking

1.1. IIASA Level Changes as of 2021 as part of the Research Plan 2021-24

At the start of 2021, IIASA saw a major change in its research organization's structure. The 9 Research Programs that existed until the end of 2020 where rearranged into 5 Research Programs with two entirely new Research Programs established. At the same time, the 4 Research Programs were further structured into Research Groups, a sub-structure not at IIASA before. At this point also all Program Directors (PDs) and Research Group Leaders (LGLs) were newly appointed for a 4-5 year term.

Figure 1-1 below highlights some of these changes. On the left-hand side, you see the earlier 9 Research Programs and, on the right, you see the new structure. The arrows indicate major movements of groups of scientists from the old to the new structure. Some previous programs (such as the air pollution and water programs) moved largely unchanged as a group to become a new RG under a newly composed program, while others (such as the Risk and Resilience Program) split up to form two different RGs under to different programs. This reallocation followed a complex process of negotiations under which researchers could also express their own preferences for their new affiliations. An important objective of this process was also to give mid-career researchers a better chance to lead their own groups and acquire management experience.

The Research Plan 2021-2024 summarizes the focus of the programs as follows:

Open access to data and models enables the flexible linking and re-linking of models and will also spur collaboration beyond IIASA. For example, the Energy, Climate and Environment Program continued it's open model strategy moving its main modelling framework fully open access, creating an international user community of scientists and decision-makers, who can co-design research with IIASA.

Much of the plan is about engine alignment: making sure that existing IIASA expertise is fully engaged with global issues, capturing the full complexity and heterogeneity of the challenges we face, and increasing the co-design of research with stakeholders. The Strategic Initiatives Program explicitly aims to boost research that combines expertise across the Institute's research programs and addresses priority areas of multiple National Member Organizations.

Some components of the research approach are being heavily upgraded. To bolster IIASA's analytical toolkit, the Advancing Systems Analysis Program will develop new systems tools including those that involve data science, machine learning, agent-based modelling, and decision support. It will also fill data gaps such as those related to monitoring the Sustainable Development Goals by improved earth observation technologies, citizen science, and novel data sources.

The Biodiversity and Natural Resources Program will give us much more power to explore the natural world. Its integrated biosphere model will encompass forest, farms, rivers, coasts, and biodiversity; and combine with existing IIASA expertise to untangle the nexus of food production, land and ecology conservation, water security, climate and disease.

The expanded Population and Just Societies Program will focus on equity, justice, and human wellbeing. The research activities take an inclusive, participatory approach, engaging with stakeholders to understand differing values around the world in an attempt to codesign what a just and equitable society should be while considering the health of the planet.

Insights on population dynamics and heterogeneities along with others from across all programs will help to inform the new Economic Frontiers Program, investigating how to shift economic activity to more just, resilient and sustainable patterns and what changes to institutions and policies need to be undertaken to secure such changes.

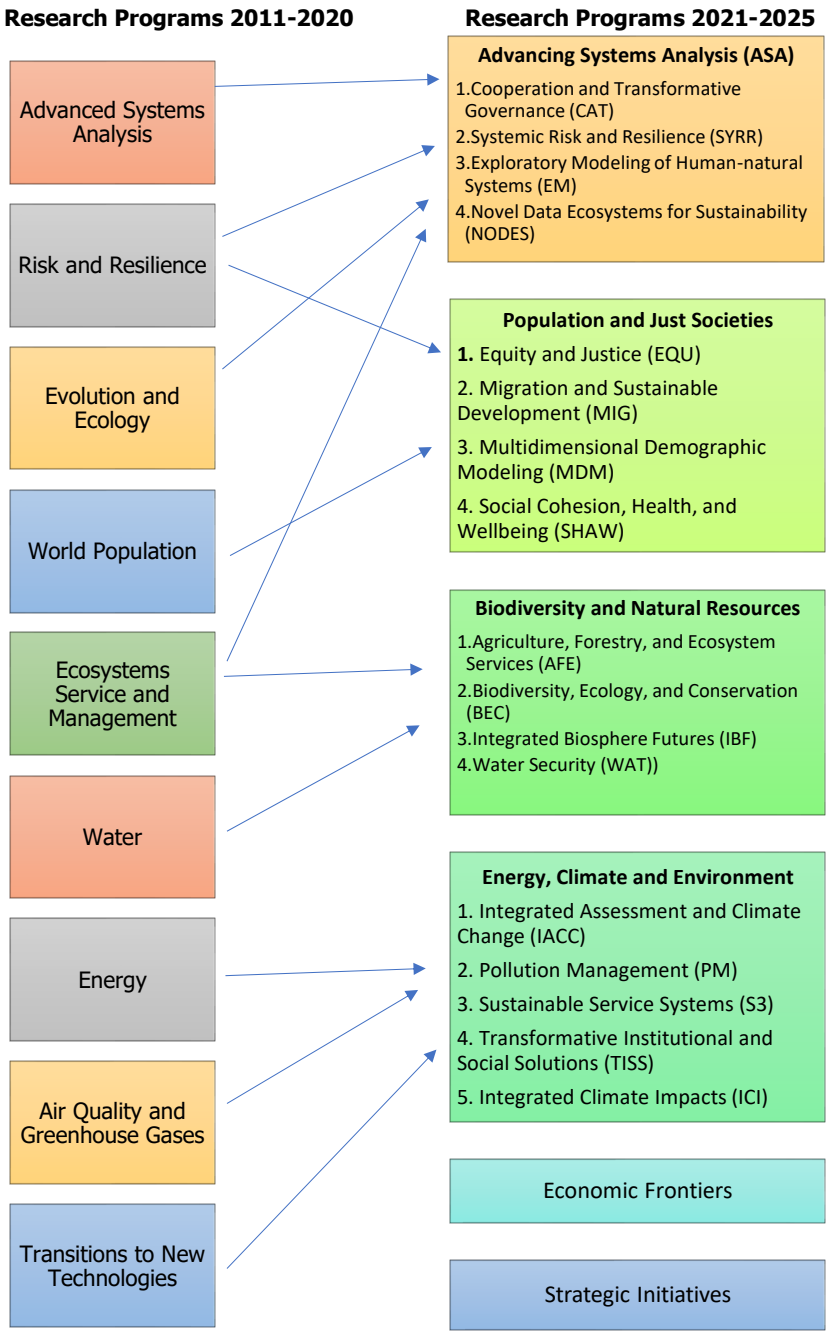


Figure 1-1. Restructuring of IIASA Research Programs in 2021

In addition to this reorganization of existing research at IIASA, two entirely new programs were formed, Economic Frontiers (FT) as a group that should strengthen IIASA expertise in the field of economics and Strategic Initiatives (SI) as an internal funding mechanism for bottom up proposed research projects which have a strong focus on involving IIASA national and regional member organizations and help to empower younger researchers to develop their own projects.

Altogether, the research plan aimed to help IIASA inform policy with the best science: enabling decision-makers to balance human needs with the laws of nature, and build sustainable, resilient societies. The goal was supported by further strengthening its collaboration with the broader scientific community, adopting transdisciplinary approaches, and enhancing system analysis capacities where needed.

This new structure (Figure 1-2) was the basis for the IIASA Research Plan 2021-24 which has been described in detail in a separate document approved by the IIASA Council in 2020 and against which this self-assessment report describes the actual activities that have happened over the last four years. More precisely this report covers the period from January 2021 to April of 2024.

This report was produced in May 2024 and after a section on Institute wide activities will cover all six IIASA Research Programs in alphabetical order and under each Program describes the typically four Research Groups that make up these programs. In addition to concise descriptions of the research activities each RG was invited to produce a SWOT analysis with all staff members contributing. Extensive appendices then give more detailed information with a specific focus on scientific publications as well as science to policy outreach.

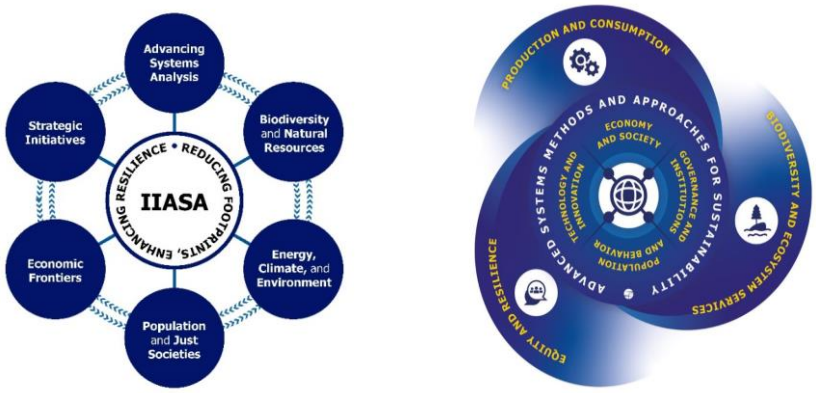


Figure 1-2. The six new programs (left) will address the seven research themes (right) of the IIASA Strategy 2021-2030

1.2. Funding available for IIASA 2021-2024

The following Table 1-1 IIASA Financial Information 2021-2024 shows IIASA's revenue and expenditure trends since 2021. During this period, a significant increase in income can be observed, with figures rising by nearly 15% between 2021 and 2023, and a continuation of this trend expected in 2024. The main driver behind this development is income from external contracts and grants, which has seen a steep upward curve in recent years. Research

expenditure increased by over 25% between 2021 and 2023 and is projected to rise again in 2024.

Table 1-1 IIASA Financial Information 2021-2024

Budget Line Item (Euro)	2021	2022	2023	2024 Budget
NMO/RMO Membership Contributions	10,930,500	11,105,500	10,155,500	10,650,000
Income from Ext. Contracts & Grants	11,412,184	12,910,545	15,083,399	16,800,000
Other Income and Release of Reserves	440,195	353,997	680,628	1,340,000
TOTAL INCOME	**22,782,879**	**24,370,042**	**25,919,527**	**28,790,000**
Research	14,321,639	15,208,198	18,148,206	20,465,000
Scientific Services	3,018,251	3,087,061	3,091,084	3,255,000
Institute Governance	1,318,887	1,222,636	1,264,146	1,540,000
Administration Services	1,827,035	1,886,698	2,224,286	2,235,000
Sundry Expenditure	1,274,320	2,469,328	1,447,729	1,295,000
TOTAL EXPENDITURES	**21,760,132**	**23,873,921**	**26,175,451**	**28,790,000**
CHANGE IN NET ASSETS	**1,022,747**	**496,121**	**-255,924**	**0**

1.3. Key Institute Level Events 2022-24

1.3.1. Presentation of IIASA Flagship Report

During the period covered in this report IIASA celebrated the 50th anniversary of its establishment in 1972. This was marked by a series of events in member countries (see next section) as well as by the production of a substantive Flagship Report attempting to provide a summary of key IIASA contributions over its history.

On 13 September 2023, IIASA launched this Flagship Report, entitled "Systems Analysis for Sustainable Wellbeing. 50 Years of IIASA Research, 40 Years After the Brundtland Commission, Contributing to the Post-2030 Global Agenda" at an official UN event in the framework of the 78th session of the UN General Assembly and the Sustainable Development Goals mid-term review.

The IIASA Flagship Report chronicles the extraordinary 50-year journey of IIASA as a globally renowned institute providing systems analytical expertise on complex global challenges. Co-sponsored by the Permanent Missions of Austria and South Africa to the UN and supported by the Department of Science and Technology of South Africa, the launch event unveiled crucial insights from the report. Notably, the publication features a foreword contribution by H.E. Alexander Van der Bellen, the Federal President of the Republic of Austria, who has been a steadfast supporter of IIASA and its research initiatives.

The launch event brought together policymakers, scientists, and representatives from various sectors to discuss the report's key aspects and the importance of advancing the 2030 Agenda. Several leading IIASA researchers and high-level collaborators including Csaba Kőrösi, President of the 77th session of the UN General Assembly; Stefan Pretterhofer, Deputy Permanent

Representative of Austria to the UN, Sepo Hachigonta, Director of Strategic Partnerships, National Research Foundation of South Africa; Nyovani Janet Madise, Director of Research for Sustainable Development Policies and Head of the Malawi office, African Institute for Development Policy (AFIDEP); and Adil Najam, President of WWF International, participated as speakers.

The report places significant emphasis on the 2030 Agenda, its 17 Sustainable Development Goals, and the ultimate end of achieve sustainable wellbeing for all. The report offers a comprehensive perspective on the interconnected challenges and opportunities that humanity faces. The publication is organized into six parts covering the main IIASA research traditions in the fields of population and human capital, biodiversity, ecosystems and food security, as well as energy, technology and climate change. Since IIASA always looked into the future, it also provides a history of thinking about the future. It also addresses future challenges and possible solutions from today's perspective and presents a new reduced form global systems model with wellbeing indicators as the critical outcome variables. In this way it also tries to make a contribution in putting the notion of "sustainable wellbeing" on the table as a possible unifying concept for the post-2030 global agenda.

1.3.2. Events marking the 50th anniversary of IIASA in IIASA member countries

21 February 2022; United Kingdom - webinar on biodiversity from a systems analysis perspective

This virtual event jointly organized by IIASA and UK Research and Innovation (UKRI) highlighted the significance of biodiversity-related research that could benefit systems thinking. A critical dialogue between IIASA researchers and the UK community addressed the need for systemic changes to bend the curve of ongoing biodiversity loss.

1-2 March 2022; Jordan - Workshop on systems analysis: To tackle global challenges and achieve the Sustainable Development Goals (SDGs)

IIASA scientists shared their experiences in the use of systems analysis to tackle global challenges through systems thinking, models and scenarios, and other practical applications with the Jordanian research community during this virtual anniversary event. The workshop helped to build Jordanian capacity in systems analysis.

7 April 2022; Austria - Sustaining biodiversity: A challenge for science and policy

Researchers from IIASA and the Austrian scientific community gathered for this hybrid scientific exchange to highlight the importance of biodiversity and citizen science initiatives, including a critical reflection on the current trends in biodiversity science and policy, and their implication on environmental governance.

27 April 2022; Israel - Workshop on models for environmental and energy policy analysis

This event gave IIASA researchers and Israeli colleagues the opportunity to discuss energy and integrated assessment modeling within the MESSAGEix framework. Discussions also explored development scenarios for the Israeli energy sector, energy transport analysis, and air quality co-benefits.

26 May 2022; USA - Workshop on international cooperation for global challenges: 50 years of building research bridges at IIASA.

IIASA delegates and members of the US scientific community gathered in Boston to reiterate the importance of international research cooperation and its pioneering role as an instrument of science diplomacy. The event also provided an opportunity for US alumni of the IIASA Young Scientists Summer Program (YSSP) to share their experiences and accomplishments as participants of the program.

2 June 2022; Finland - Seminar on systems analysis: Science-based support for policymakers

The Finnish IIASA Committee, the Academy of Finland, and IIASA jointly organized this hybrid event in Finland, which welcomed speakers from IIASA and Finland, as well as IIASA alumni in the country, to broaden networking opportunities and strengthen links with the Finnish research community.

7 June 2022; Iran - Seminar on systems analysis

This event was co-organized by IIASA and the Iran National Science Foundation (INSF) to show how global, regional, and local challenges can be addressed with systems analysis. It also highlighted systems approaches to deal with urban risk, energy, and climate issues. The event took place online and featured two keynote presentations and a panel discussion.

14 June 2022; IIASA 50th Anniversary Science Diplomacy Event: The Need for International Scientific Cooperation and Multilateralism

IIASA organized this high-level science diplomacy event in Vienna's beautiful Museums Quartier to discuss the crucial role of international scientific cooperation in enabling researchers to access additional expertise and gain new perspectives on research, unlocking scientific discoveries, and promoting scientific advancement for the benefit and interest of all humankind. Discussions during the event resulted in the Vienna Statement on Science Diplomacy, which has since been endorsed by more than two hundred eminent personalities from the academic and policymaking community.

10-12 August 2022; IIASA 50th Anniversary International Conference in India.

This hybrid conference in New Delhi was co-hosted by IIASA and the Technology Information, Forecasting and Assessment Council (TIFAC), with partners from China, Iran, Japan, and Jordan. It built on the expertise and interlinkages between the systems analysis communities in Asia to discuss and analyze transformative approaches to achieving sustainability across multiple stakeholders, sectors, and regions.

4 October 2022; Happy birthday IIASA

On the institute's official 50th birthday, IIASA hosted an informal celebration for those who compose and define the DNA of the institute: current IIASA staff, local alumni, IIASA Distinguished Visiting Fellows, collaborators from the Austrian scientific landscape, as well as local supporters from the Laxenburg community. Highlights of the event included a beautiful birthday cake and the sealing of a time capsule with, among other keepsakes, messages from IIASA staff and alumni to be opened after 25 years.

12 October 2022; Korea - IIASA joint conference on systems analysis as a global approach

IIASA and the National Research Foundation of Korea jointly hosted this hybrid conference in Seoul through the Korean IIASA Committee to highlight and consolidate ongoing collaboration. The conference also served to introduce the YSSP and other IIASA capacity building programs to the Korean academic community and to discuss an expansion of the research agenda.

28 October 2022; Alumni Event in Budapest, Hungary celebrates the 50th Anniversary of IIASA

IIASA alumnus István Kiss brought together the IIASA community at the Hungarian Academy of Sciences in collaboration with the John von Neumann Computer Society and the International Institute for Applied Systems Analysis (IIASA) to celebrate the institute's 50th Anniversary.

16-17 November 2022; IIASA-OeAW Conference on systems analysis for reducing footprints and enhancing resilience

The two-day hybrid 50th anniversary event was co-organized by IIASA and the Austrian Academy of Sciences (OeAW). It was held at the Austrian Academy of Sciences in Vienna and opened by the Federal Minister of Education, Science, and Research of the Republic of Austria. The conference attracted over 550 participants from all over the world and demonstrated how systems analysis can contribute to solving many of today's global challenges and explored the future of this transdisciplinary field.

24 November 2022; IIASA 50th anniversary event in Slovakia

Albert van Jaarsveld, former IIASA DG, introduced the audience to IIASA, its history, advanced models and tools under a lecture titled "Global change and systems solutions" to the teaching staff and students of Comenius University, Bratislava, Slovakia. IIASA and Comenius University signed a Memorandum of Understanding for Scientific Cooperation to allow both institutions to develop closer collaboration through the exchange of expertise and conduct of research to better optimize the synergies from their respective fields of specialization.

4-7 December 2022; IIASA 50th Anniversary event in South Africa during the World Science Forum

IIASA collaborated with the South African National Research Foundation (NRF) to host two events to promote the 50th Anniversary of IIASA and systems analysis in advance of the World Science Forum. The first, a high level panel discussion, aimed to position the IIASA Sub-Saharan Africa Regional Member Organization (SSARMO) with heads of research councils in Africa and reflect on priority focus areas on the continent, while the second, an academic symposium, presented highlights of selected projects and highlighted the application of system approaches and skills development in projects.

12 May 2023: IIASA alumni reunion marks IIASA 50th Anniversary

The IIASA Resources and Environment Area/Environment Program (REN/ENV) 1970s/1980s reunion took place on 12 May 2023, marking the 50th Anniversary of the institute's founding. The event brought together former staff members, friends, and scientists in a heartfelt commemoration. Led by Martin Parry, a distinguished researcher and key contributor to the IIASA REN and EV programs, along with Jesse Ausubel, Walter Foith, JoAnne Linnerooth-Bayer, and Elisabeth Jaklitsch, the reunion aimed to create a meaningful platform for reflection and reconnection among alumni.

6 November 2023: Austrian Academy of Sciences: 50 years of IIASA membership

As the IIASA host country, Austria has always been a close partner and has been providing a home to the institute in Laxenburg since its founding in 1972. The Austrian Academy of Sciences has been a National Member Organization (NMO) since 1973.

The anniversary ceremony reflected on the institute's origins, underlining its founding principles as a vital bridge between East and West, along with its significance for Austria and the Austrian Academy of Sciences. Additionally, the event focused on the challenges posed by an ever-evolving world, highlighting IIASA's dynamic role in this transformation. The path forward is concisely outlined in the newly released IIASA Flagship Report.

1.3.3. Other important events in which IIASA had strong presence

Commented [RK1]: I am missing in this list the IPCC approval plenaries with IIASA CLAs in 2021 and 2022. Also important to add IIASA's contribution to the IAMC conferences of 2021, 2022, 2023, which brought together many hunders of researchers at each of these events.

Commented [AL2R1]: Added.

13 - 15 April 2021:	Systems Analysis in EurAsia | IIASA
12 - 15 June 2021:	Sustainability Research and Innovation Congress 2021 | IIASA
5 - 7 July 2021:	Vienna Energy Forum 2021 | IIASA
3 - 6 October 2021:	Citizen Science at the UN World Data Forum | IIASA

31 Oct - 12 Nov 2021: UN Climate Change Conference (COP26) | IIASA

5 - 10 December 2021: International Population Conference 2021 | IIASA

IIASA at IUSSP International Population Conference 2021 | IIASA

22 December 2021: Launch of the Northern African Applied Systems Analysis Centre | IIASA

6 - 9 April 2022: IIASA at the PAA Annual Meeting 2022 | IIASA

23 - 27 May 2022: IIASA at EGU 2022 | IIASA

6 - 16 June 2022: IIASA at the UNFCCC Bonn Climate Conference | IIASA

20 - 22 June 2022: Scenarios Forum 2022 | IIASA

20 - 24 June 2022: Sustainability Research and Innovation Congress 2022 | IIASA

3 October 2022: First General Assembly of the Citizen Science Global Partnership | IIASA

6 - 18 Nov 2022: IIASA at UNFCCC COP27 | IIASA

7 - 19 December 2022: IIASA at the United Nations Biodiversity Conference | IIASA

12 - 15 April 2023: IIASA at the PAA Annual Meeting 2023 | IIASA

23 - 28 April 2023: IIASA at EGU 2023 | IIASA

19 - 21 June 2023: IIASA at the 6th European Climate Change Adaptation Conference 2023 | IIASA

26 - 30 June 2023: Sustainability Research and Innovation Congress 2023 | IIASA

12 - 29 Sep 2023: IIASA at the UNGA78 Science Summit | IIASA

28 - 30 Sep 2023: IIASA at IDRiM 2023 | IIASA

2 - 3 Nov 2023: International Vienna Energy and Climate Forum | IIASA

14 – 16 Nov 2023: IIASA active contribution to IAMC

30 Nov - 12 Dec 2023: IIASA at UNFCCC COP28 | IIASA

28 February 2024: IIASA leadership at the International Symposium on Japan's contribution to the IPCC 7th assessment cycle | IIASA

14 - 19 April 2024: IIASA at EGU 2024 | IIASA

17 - 20 April 2024: IIASA at the PAA Annual Meeting 2024 | IIASA

1980 - Present: IIASA contribution to IPCC

1.4. IIASA Key statistics

1.4.1. IIASA personnel

In 2021, IIASA introduced a new process for the classification of profiles of scientific employees under the IIASA Policy on Adapted Profiles of the European Framework for Research Careers, based on the European Framework of Research Careers. The policy is used to evaluate the development of an individual researcher's demonstrated competencies, skills, capabilities, achievements, and contributions. The European Framework of Research Careers distinguishes and describes four broad profiles during a researcher's career development. The four profiles have been adapted for use at IIASA and are named: Researcher (R1), Research Scholar (R2), Senior Research Scholar (R3), and Principal Research Scholar (R4). The institute also recognizes employees working as software professionals in the 3 categories: Research Software Developer (S1), Senior Research Software Developer (S2), and Research Software Engineer (S3).

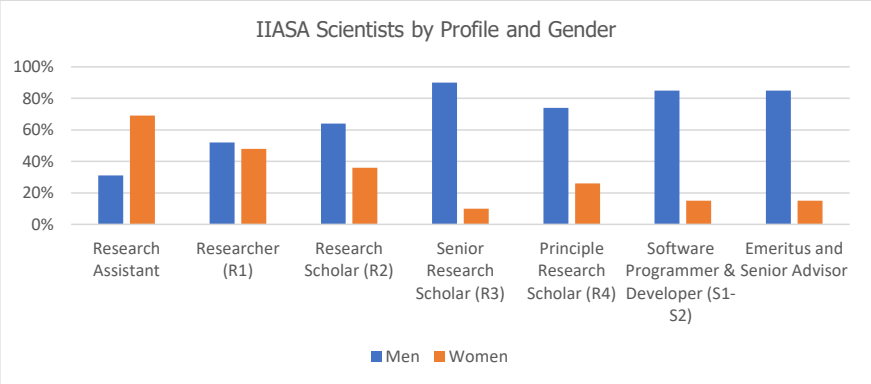


Figure 1-3. IIASA scientists by profile and gender (data as of 31 December 2023).

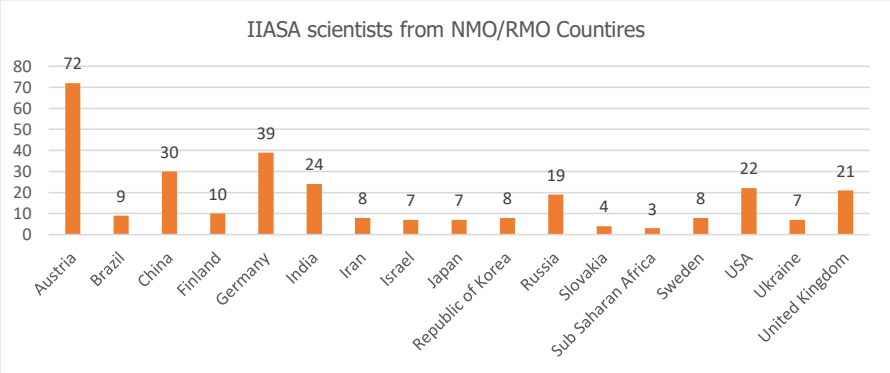


Figure 1-4. IIASA scientists from NMO/RMO (data as of the first quarter of 2024).

In the last quarter of 2023, IIASA introduced a new grading system for its operational employees, from O1 to O7, under the Grades of Operational Positions Policy. This milestone was achieved through a collaborative effort, with valuable insights and inputs gathered from multiple meetings with heads of departments, units, and program directors, and Q&A sessions with employees. The new Grading Policy is a step forward, in supporting various human resources processes within our institute. It applies to all operational positions, encompassing positions within administrative departments and units, non-scientific positions within research groups and programs, and the institute's non-executive Directorate staff.

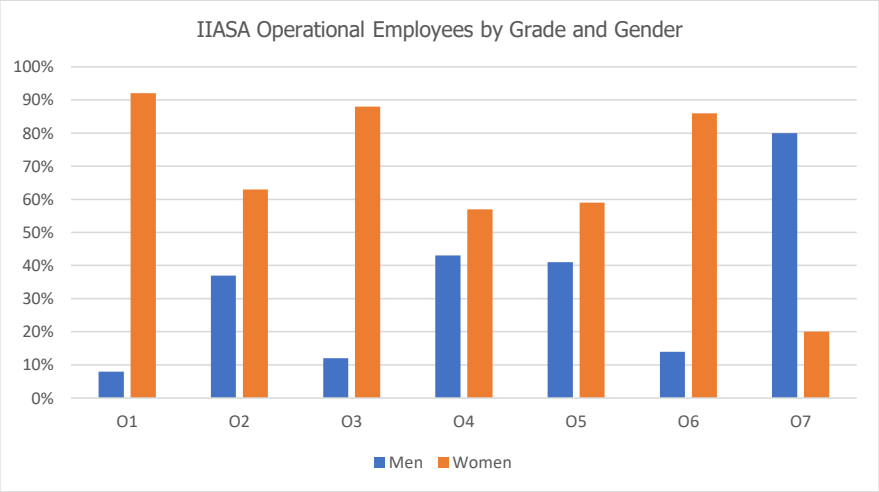


Figure 1-5. IIASA operational employees by grade and gender (data as of 31 January 2024).

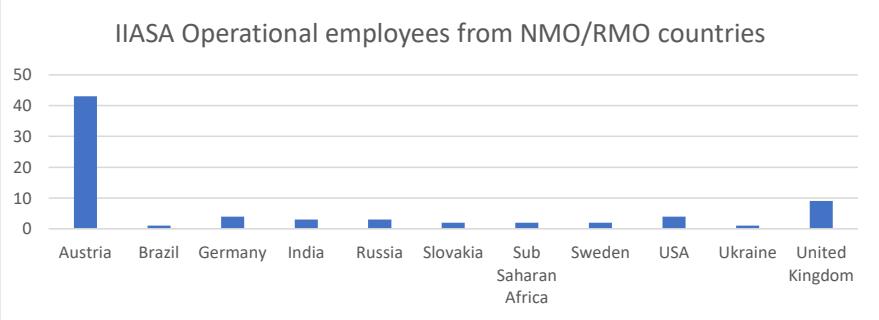


Figure 1-6. IIASA operational employees from NMO/RMO countries (data as of the first quarter of 2024).

As of the end of 2023, IIASA had 378 employees and 152 guests. Among the employees, 265 are scientists, and 110 are operational. Among scientist employees, there were 91 women and 174 men. Among operational employees, 69% are women. IN May 2024, IIASA passed the threshold of 400 employees.

1.4.2. Publications Summary

As a signatory to the Berlin Declaration on Open Access to Knowledge in the Sciences and Humanities, IIASA is committed to providing unrestricted and cost-free online access to its scientific publications and data for all users and researchers. To ensure good data management and open access to all IIASA research, the institute maintains an institutional publications and data repository in the IIASA Publications Repository (PURE) for research produced by IIASA affiliated researchers.

The institute helps researchers find funds to cover publication fees through grants or other funding opportunities, and additional financial support is provided through dedicated IIASA open access funding. In addition, IIASA encourages its researchers that publish in books to negotiate open access and provides advice and support in this regard. As such, IIASA encourages researchers and software developers to provide open access to the models and tools, following the spirit of Open Science, whenever possible. The inventory of models and tools developed and maintained by IIASA affiliated researchers is available at the institute's dedicated webpage.

Table 1-2 Number of IIASA Publications 2021-2024 (data from SCOPUS)

	2021	**2022**	**2023**	**As of 31 May 2024**
Total Publications*	734	748	736	297
Refereed publications	555	503	484	232

* Detailed lists of all publications are given in the Programs specific documents.

IIASA scientists from across various research programs have been continuously recognized in the annual Highly Cited Researchers list from Clarivate, with 12 researchers in 2021, 11 researchers in 2022 and 9 researchers in 2023. In 2022, Yoshihide Wada is one of only 219 researchers recognized in two fields (environment and ecology, and geosciences), while in 2021 and 2022, Keywan Riahi is one of only 28 researchers recognized for showing exceptionally broad performance being highly cited in three or more fields (environment and ecology, geosciences, and social sciences).

Climate change and energy were among the topics that received the most media attention in 2023. IIASA researchers contributed to six out of the 25 most mentioned papers in online news articles, as well as on blogs and social media platforms based on an analysis performed by Carbon Brief using Altmetric data.

1.4.3. Benchmarking

Following the request by the IIASA Council, management has put together some statistics that compare IIASA scientific output and policy impact to other international institutions working in a similar field as well as three major research institutions in Austria. Due to the different size of these institutions the statistics are standardized by Full Time Equivalents (FTE) of their total staff (no differentiation between scientists and non-scientists possible). Universities have not been included in this comparison because they have a very different mandate.

The figures below show that both in terms of scientific publications and citations as well as in terms of policy impact (based on the Overton data base that tracks more than a thousand different sources of policy documents from 180+ different countries) IIASA is among the very top research institutes. When combining both dimensions – publications and policy impact – IIASA turns out to be the best performer.

Table 1-3 List of organizations for benchmarking and their full time equivalent (FTE). Data of FTE is based on the annual report 2023.

	Name of Institutes	**FTE (all staff)***
IIASA	International Institute for Applied Systems Analysis	267.21
CGD	Center for Global Development - USA	85
DIE	German Development Institute - Germany	96
NIES	National Institute for Environmental Studies - Japan	298
ODI	Overseas Development Institute - USA	264
PBL	Netherlands Environmental Assessment Agency – The	257
PIK	Potsdam Institute for Climate Impact Research -	407
SEI	Stockholm Environment Institute - Sweden	322
In Austria		
AIT	Austrian Institute of Technology	1,241
ÖAW	Austrian Academy of Sciences	1,517
ISTA	Institute of Science and Technology Austria	999

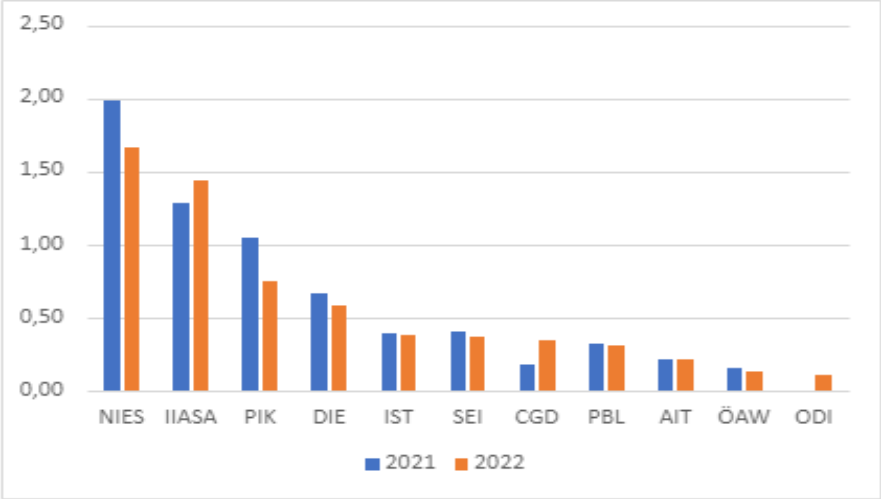


Figure 1-7. All (co-authored) peer-reviewed publications per total FTE (based on SCOPUS 2021-2022).

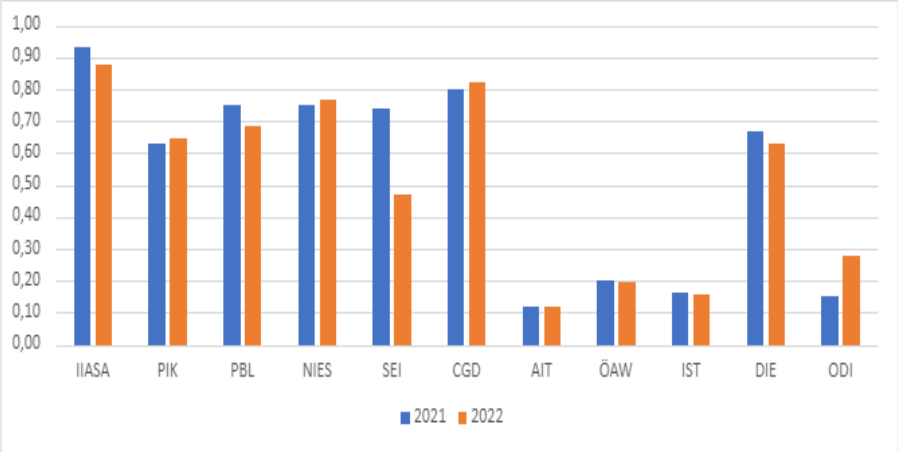


Figure 1-8. Institutional H-index per FTE, as of 03 October 2023. Data based on SCOPUS.
Note: The institutional h-index is based on all documents by a specific organization that are indexed in SCOPUS. (e.g., an h-index of 236 means that of the total of documents considered for the h-index, 236 have been cited at least 236 times).

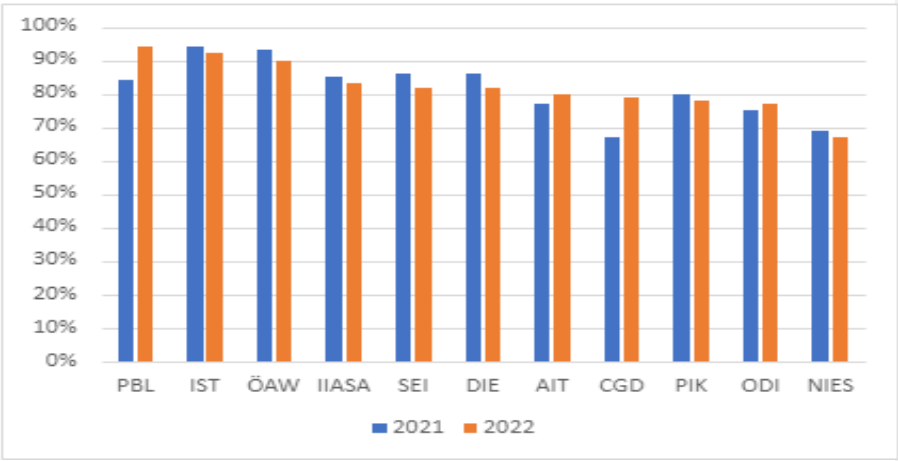


Figure 1-9. Proportion of peer-reviewed publications with open access. Data based on SCOPUS.

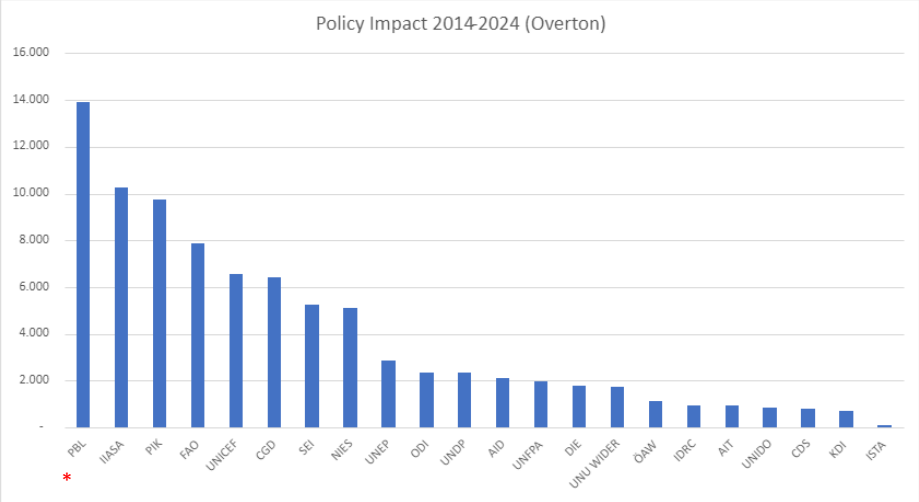


Figure 1-10. Policy Impact (Source Overton 2021-2024)
Note: Overton tracks more than a thousand different sources of policy documents from 180+ different countries. The results represent the number of times an organization's research is cited in policy documents.
* A huge proportion of PBL's output is for the national Dutch context

	Name of the organization for Policy Impact benchmarking
AID	United States Agency for International Development
AIT	Austrian Institute of Technology
CDS	Centre For Development Studies
CGD	Center for Global Development
DIE	German Development Institute
FAO	Food and Agriculture Organization of the United Nations
IDRC	International Development Research Centre
IIASA	International Institute for Applied Systems Analysis
ISTA	Institute of Science and Technology Austria
KDI	Korea Development Institute
NIES	National Institute for Environmental Studies
ÖAW	Austrian Academy of Sciences
ODI	Overseas Development Institute
PBL	Netherlands Environmental Assessment Agency
PIK	Potsdam Institute for Climate Impact Research
SEI	Stockholm Environment Institute
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFPA	United Nations Population Fund
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
UNU WIDER	World Institute for Development Economics Research

2. Program: Advancing Systems Analysis (ASA)

2.1. Overall Program Achievements 2021-2024

2.1.1. Research and internal collaboration

The ASA Program develops and deploys advanced systems-analytical approaches to tackle the complexity of pressing sustainability challenges. We operate at the intersection of science, data, technology, and policy & practice to produce relevant and timely outcomes for stakeholders and funders.

ASA builds on IIASA's rich tradition in operations research, optimization, and optimal control—core methodologies that served as the backbone of systems analysis in the 20th century. In response to the new realities of the 21st century, including the funding landscapes that prioritize applied research, we have embraced a much broader focus. Our methodological toolbox has expanded to include game theory, complexity science, data science, and machine learning, as well as 'soft' systems-analysis approaches. The institutional reorganization in 2020 consolidated scientists and teams from across IIASA, whose productivity and impact stem from working on diverse applications. Uniting these applications is the deployment of a particular methodology or addressing cross-cutting issues such as resilience or cooperation.

Of 496 articles by ASA researchers since 2021,

- 191 (39%) match the search criteria 'economic AND environmental AND social AND system'.
- 263 (53%) articles contain the term 'co-production'.

We leverage a diversity of methodologies and work with different applications across multiple domains to fuels innovation and bolster our ability to respond to the evolving landscape of societal needs with high levels of agility. ASA research thrives on interdisciplinarity, bringing together researchers from diverse backgrounds in a flexible and dynamic research environment to delve into the intricate interconnections of socio-economic-environmental systems. Transferring methods across disciplines enables harnessing new perspectives to obtain novel insights.

Furthermore, our research is increasingly transdisciplinary, conducted in partnership with policy, practice, civil society, and the private sector. Genuine transdisciplinarity signifies that we do not merely act as consultants providing research to clients for their agendas; rather, we engage in co-creating agendas and charting the directions of inquiry and action in collaboration with our partners.

ASA continuously conducts horizon scanning to identify promising novel matches between methodologies and applications across all thematic areas of the IIASA research agenda. Proofs-of-concept of new methodologies and pilot applications test the outcomes of horizon scanning efforts and showcase their potential. Successful approaches are further developed either within the program or in other IIASA or partner settings.

Progress towards objectives
The Research Plan 2021-2024 has set out five interrelated objectives for ASA to organize its activities operationalizing the program's ambitious vision and mission. Over the review period, through the collective effort of its research groups, ASA has made substantial progress in all five objectives.

Amidst the burgeoning landscape of **new data and data-science tools**, one of our objectives was to leverage these advancements to better **diagnose vulnerabilities and barriers hindering sustainable development**. Significant progress has been made towards comprehensive environmental monitoring through the integration of Earth observation with Citizen Science and Machine Learning[1,2,3]. Highly detailed maps of land use and land cover (LULC) allow rapid assessment of anthropogenic impacts on ecosystems[4]. Pioneering novel

applications beyond LULC have offered insights into socio-economic development patterns[5,6]. Deeper understanding of local communities' resilience to climate-related disasters has emerged through innovative utilization of citizen science powered by machine learning[7]. Initial investigations with data from social media have illustrated high potential of this novel source of unique data in capturing real-time sentiments of individuals regarding pressing societal challenges, for example, energy and food security[8].

Of 496 articles by ASA researchers since 2021, 202 (41%) contain the phrase "we develop a new model".

Given that modelling serves as a cornerstone methodology to inform decisions regarding socio-economic-environmental systems, our second objective was to advance our **suite of modelling frameworks** to bolster our ability to promptly address rapidly evolving policy needs and societal challenges. Ensuring high agility necessitates the development of **modelling frameworks** spanning **various levels of complexity**. Stylized models describing complex processes with a few equations can be used for hypothesis testing and to explore the richness of system's dynamics including non-linearities, multiple equilibria, and tipping points, without demanding extensive development time or computational resources. For example, stylized models developed during the initial months of the COVID-19 outbreak provided insights into the trade-offs associated with policies aimed at mitigating the pandemic[9,10,11,12]. On the other hand, agent-based models (ABM) include detailed representation of a large number of heterogeneous entities, their complex behaviours, and dynamic interactions. For example, our macro-economic ABM (MacroABM) evaluated diverse socio-economic impacts of disruptive events such as migration[13] and floods[14] in Austria across sectors and household groups, offering a level of detail suitable for targeted policy making. Notably, our ABM simulations often require using high-performance computing (HPC) or other advanced technologies[15].

Since 2021, ASA made publicly available 44 datasets and 14 model codes, mainly via GitHub.

Making a real-world impact necessitates transcending disciplinary boundaries and working in partnership with stakeholders beyond the realm of science. ASA researchers advance feasible and effective ways of **engaging with policymakers, the private sector, civil society, and citizens**. We engage with policymakers in processes of co-production of theories of change, data, interventions and insights[16,17,18,19]. The use of pre-developed processes and tools facilitates deliberations and enhances impact[20,21,22,23]. Furthermore, we involve laypeople in citizen science projects which typically involve large-scale campaigns requiring specially designed web-based tools[24]. ASA has amassed extensive experience in developing such tools, which not only aid us in future research, but are also made available to a wide community[25]. While the private sector remains a rather rare partner for publicly funded science, ASA seeks to harness collaboration opportunities as companies embrace greater social responsibility. For example, ASA has partnered with the IT sector to jointly explore novel machine learning and AI tools[1]. Or, our collaboration with the (re)insurance sector strives to address the rapidly evolving landscape of socio-environmental risks and resilience[26].

We combine data, interdisciplinary modelling, and transdisciplinarity to analyze increasingly **systemic social-ecological risks** and to support decisions aimed at **enhancing resilience**. The 2007-2008 financial crisis sparked a surge of global research into systemic risk focused on the financial sector. ASA has consistently provided research to inform the mitigation of such risks and fortify financial systems for the future[27]. In our ever more interconnected world, many other risks are becoming increasingly systemic. Interconnections among system components can serve as a key driver of systemic risk, whereby the malfunction of one part can propagate throughout the entire system, posing a threat to its functionality. In our ever more interconnected world, many other risks are becoming increasingly systemic, where the malfunction of one system's component can spread and threaten its overall functionality. ASA researchers generated guidance, applications and

Full texts are available in the IIASA's publication database PURE for 372 (75% of a total of 496) articles by ASA researchers since 2021.

policy proposals for the management of increasingly systemic and existential multi-hazard risk in the context of climate change[28,29,30,31]. Additionally, we innovate approaches for analyzing urban resilience as an emergent property from interconnections among economic activities as well as carbon, water and energy metabolisms within cities[32,33,34]. Engagement with our key stakeholders, including policymakers, the private sector, and citizens ultimately serves to **enhance trust and shared understanding** of systems analysis methods and tools and has at various times strongly contributed **to policy impact**. We share the view that the adoption of an **open science** paradigm is not only a prerequisite for trust but also a societal responsibility of science and hence we strive to make our research outputs as open as possible. Notably, ASA is leading a project within IIASA's Strategic Initiatives Program that analyzes how trust in science can be facilitated through citizen engagement.

Highlights of academic achievement

Since 2021, ASA researchers authored and co-authored 496[1] articles published in international journals, including 3 articles in Science, 7 in Nature, and 6 in PNAS (see Appendix F, Table F1 for the full list of ASA publications and Table F2 for the list of journals, where ASA researchers published most frequently). Prominent, highly cited ASA researchers include Michael Obersteiner (H-index 88), Ulf Dieckmann (H-index 64), Linda See (H-index 59), and Steffen Fritz (H-index 59)[2]. Michael Obersteiner maintains consistent presence on the Highly Cited Researchers list by Clarivate. Seven ASA researchers were recognized in the 2023 Research.com Top Scientists ranking.

Furthermore, ASA research has been recognized by prizes and awards. For example, in 2021 Sebastian Poledna won the paper competition in complexity and macroeconomics from the Rebuilding Macroeconomics (RM) Network. Brian Fath received the 2022 University System of Maryland Board of Regents Faculty Award for Excellence in research, scholarship, and creativity. Three ASA researchers were among finalists of the 2021 Decision Analysis Practice Award.

Collaboration with other IIASA programs

ASA expertise and research approaches are often complementary to IIASA's other research programs providing a strong foundation for mutually beneficial collaboration. Collaborations include multi-year joint research endeavors, specific joint projects, and bottom-up initiatives of researchers.

Joint publications can serve as a proxy indicator of collaboration. Since 2021, 18% of papers co-authored by ASA researchers included collaborators from the BNR program, 10% from ECE, 7% from POPJUS, and 2% from EF.

To name a few examples, with our competence in Earth Observation, we collaborate with BNR on using these data to inform land use models. Our expertise in risk analysis is utilized in collaborative research with POPJUS, ECE, and BNR focusing on global climate, flood, forest fire, drought, and health risks and resilience[36,37,38]. Collaboration with EF explored optimal pathways in economic growth models using optimal control[9,10,11,12]. Evolutionary game theory has been used for modeling of eco-evolutionary vegetation dynamics, a collaboration between ASA and BNR[39]. ASA and ECE have undertaken a joint research endeavor to develop and apply a flexible medium-complexity Earth systems model[40,41].

Policy Impact and external networks

Any discussion of the societal impact of science must acknowledge the diversity of the underlying epistemological perspectives[3]. While the positivist worldview centers on the provision of actionable science-based recommendations, the constructivist approach sees influence through interactions, and the performative perspective emphasizes the role of 'translators'. Naturally, the actual utilization of knowledge depends on multiple factors, including the quality and relevance of research, but also the capacity of users to access and evaluate the research findings[4].

At ASA, our understanding of policy impact generally aligns with the research theory of change suggested by Belcher & Halliwell[5] (see Figure A1 in Appendix A). When designing research projects, even those which focus on advancing or development of new methodologies, we are

mindful of their potential to make conceptual, instrumental, or strategic impacts on real-world socio-economic-environmental systems, whether at global, national, or local scale.

Most of our efforts concentrate on advancing research as our 'sphere of control'. We disseminate insights from our studies to a broad audience extensively via policy briefs[42,43,44,45,46,47] and various other channels (e.g. social media, newsletters). We have embraced novel dissemination methods, such as podcasts, and also in-person interactive engagement with laypeople, including younger generation.

Once high-quality research is available, any act of meaningful interaction with it, according to the interactionism theory, can induce changes in knowledge, attitude, skills, relationships, and behaviour (KARSB) of involved partners and stakeholders, leading to impact within our 'sphere of influence'. These KARSB changes enhance the likelihood of transitions in policy and practice (instrumental impact) and, in some cases, the chance for a system change (strategic impact, i.e., our 'sphere of interest'). In most cases, strategic impact is achieved by collective effort of many scientists and scientific institutions. A prime example is the IPCC, which mobilizes the global research community to synthesise the state of knowledge on climate change, thereby shaping international climate discourses and informing policy decisions worldwide. ASA researchers made lead- and contributing-authorship contributions and supported dissemination over the most recent 6th assessment cycle[48,49].

As a testament of our scientific excellence, engagement and relevance, ASA researchers are invited to contribute to targeted science-policy processes and events, which enables conceptual and instrumental impact (see Appendixes B and C). ASA researchers have also been invited as experts to join negotiations on salient issues, such as the EU team for adaptation and Loss&Damage climate policy.

Participatory research involving stakeholders and collaborative research in partnership with decision-makers are particularly powerful channels for generating impact. Many ASA projects involve partnerships and participatory research offering effective platforms for co-creation of research and insights. Participatory research often aims at informing specific policies or decisions (instrumental impact) by identifying compromise areas or solutions that balance the diverse and often poorly understood interests and concerns of stakeholders. ASA examples include work on contested Loss&Damage climate policy, where our engagement with policy and civil society over the years contributed to the consensual decision at COP28 to set up a Loss&Damage fund[50,51]. As another example, the Master Strategy for the Energy Sector 2020-2030 in Jordan was informed by a participatory process led by ASA researchers that revealed trade-offs and identified compromise solutions acceptable for major stakeholders' groups.

In our experience, long-term close partnerships involving trustful, often informal relationship between researchers and decision-makers, provide effective channels for making impact. The adoption by the Bank of Canada our MacroABM for forecasting inflation resulted from such cooperation[52], as an example.

Partnerships are also key for science-practice implementation research. ASA engages in such research, where a prime example is the partnership with the Flood Resilience Alliance (now Climate Resilience Alliance), with ASA researchers working jointly with INGOs to conduct and validate disaster resilience measurement as well as to assess the applicability and effectiveness of resilience-enhancing interventions in 500 highly vulnerable communities in over 50 countries[7].

Science diplomacy
IIASA's Strategy 2021-2030 puts emphasis on science diplomacy, aspiring to "provide long-term scientific support and infrastructure as a neutral science-based broker on emerging global and regional challenges that can only be addressed through cooperation and collaborative work". ASA strongly shares this aspiration and initiates research with a science-diplomacy component. As one example, amidst growing geopolitical tensions, our project Emerging trade routes between Europe and Asia provided a safe environment for experts from various countries to

share their perspectives on the highly debated topic of shipping in the Arctic, facilitating mutual understanding and contributing invaluable insights for anticipating future developments[53].

At no other time has multilateral international cooperation been as crucial as it is today, yet it coincides with one of the most severe historical crises facing multilateralism. To contribute to strengthening multilateralism, ASA researchers collaborated with the Sherpa G20 India Presidency in 2022 and led the preparation of four policy papers[54,55,56,57], engaging 27 leading international experts to offer insights into the complexities of potential multilateral institutional reforms. Many of the recommendations made in these policy papers found traction and resonance in the G20 New Delhi Leaders' Declaration.

Capacity development
Strengthening the capacity of the nexl.t generation of researchers and decision-makers in systems analysis is an important dimension of ASA's impact. ASA therefore actively contributes to IIASA's capacity development and training activities. In 2021-2023, ASA researchers supervised and co-supervised 45 participants of the Young Scientists Summer Program (YSSP) with four projects receiving special YSSP awards and honorary mentions for their quality. ASA's researcher Brian Fath has been serving as the YSSP's Scientific Coordinator since 2011. Furthermore, many ASA researchers contribute to IIASA's inaugural Summer School for Systems Modeling taking place in 2024. NODES organized several introductory statistics and GIS courses for YSSPers and an open GEO hackathon week at IIASA in June 2024 for advanced students to explore geospatial analysis on HPC infrastructure.

Focusing on the current generation, since 2021, ASA's research groups conducted multiple trainings on their tools for different audiences from students to experts. For example, SYRR offered trainings to eight IIASA's MO countries on their CATSIM model that provides support for disaster-vulnerable countries for risk management decisions.

2.1.2. Program budget and staff

ASA's activities are funded primarily through third-party funding with the core funding being used for strategic investment and to support operations (see Appendix D for the ASA budget over years). To summarize, in 2021-2023, the ASA overall budget increased by 28%, and FTEs grew from 46 in 2021 to 55 in 2023, an increase of 18%.

Income from external funding increased by 40% (see Appendix E for the list of ASA projects) and core funding decreased by 22%. As IIASA's internal funding approach has been shifting towards project-based allocation, the opportunity for strategic investment into exploratory research and agile response to societal needs has been decreasing.

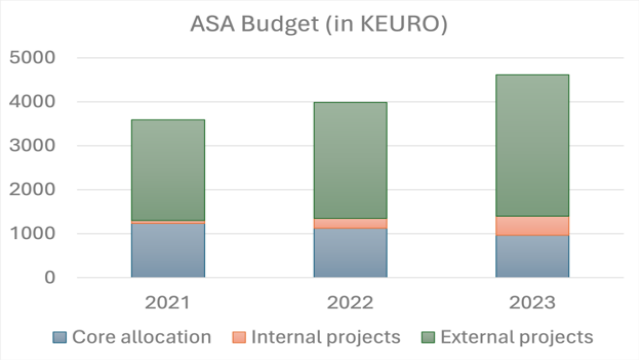


Figure 2-1 ASA Budget (in thousand Euro)

ASA generates research and societal impact through the collective effort of its scientific staff, supported by software developers, operational and other essential personnel. In 2021-2024[6], ASA employed 117 staff from 34 countries, 38% women and 62% men. ASA comprises scientists at various stages of their careers. This diversity in seniority ensures a broad range of expertise, perspectives, and mentorship opportunities, fostering a rich and dynamic research environment where fresh ideas and innovative approaches of junior scientists combine with the experience and wisdom of senior colleagues.

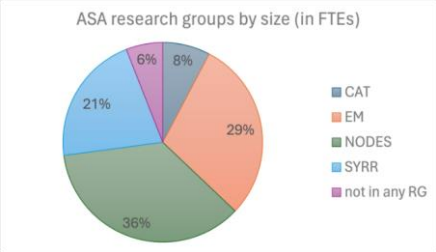


Figure 2-2 ASA Research Group by size (in FTEs)

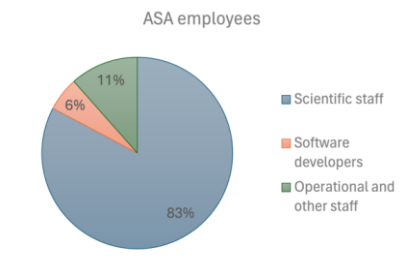


Figure 2-3 ASA Employees

In line with IIASA's spirit of an international hub, many of our researchers engage with ASA on a part-time basis, often combining it with teaching at universities or other professional commitments. Furthermore, in 2021-2024, ASA hosted 88 guest researchers from 29 countries. Part-time and guest contract arrangements allow us to connect with different communities and geographies and leverage these connections enhancing richness of our research and impact.

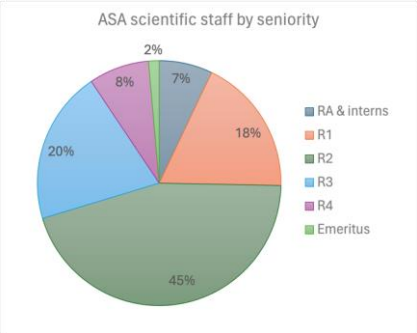


Figure 2-4 ASA scientific staff by seniority

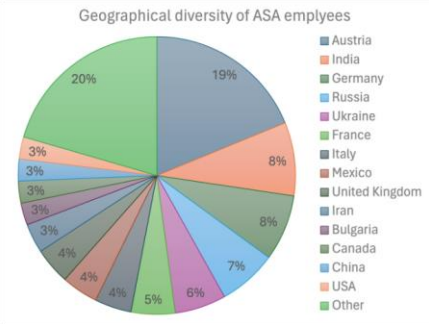


Figure 2-5 Geographical diversity of ASA employees

2.2. ASA's Novel data Ecosystems for Sustainability (NODES)

2.2.1. Summary of achievement of goals and highlights

NODES main mission as per the IIASA 2021-2024 Research Plan was to mobilize the tools of citizen and data science combined with Earth observations (EO) and other data sources to monitor, analyze, and foster progress toward the UN Sustainable Development Goals (SDGs). To achieve this, NODES has focused on three main cross-fertilizing pillars, namely: advancing the field of Citizen Science (CS); enriching EO; and exploiting the digital revolution.

Advancing the field of Citizen Science
NODES employs CS to engage people in scientific research and knowledge production, from data collection in its most basic form to fully co-created research projects. Stemming from our seminal publication in Nature Sustainability on citizen science and the UN SDGs,[58] NODES has been conducting pioneering work in the application of CS to address the significant data gaps in the SDGs, in partnership with, among others, the UN statistical offices.[59,60] This has led to a significant policy impact in the case of Ghana, where CS contributions to SDG monitoring for marine plastics are now officially recognized by the UN.[61,62] Meanwhile this approach is now being replicated in other countries in Africa, e.g., Sierra Leone, Nigeria. In addition, similar CS-based approaches are being applied to address shortcomings in SDG monitoring, e.g., health and wellbeing.[63]

NODES has contributed numerous innovative, free and open datasets to the research community via its CS platform Geo-Wiki, including datasets on land use change and forest management, among others.[64,65] These datasets are used in subsequent research by both IIASA researchers[66] and the wider research community.[67] As part of our mandate, NODES has launched multiple successful open digital CS applications (e.g., CropObserve, Street Level Validator) which are used to drive some of our ongoing research efforts, in particular on the topic of food security. Supporting these efforts, NODES has invested considerable effort in the science of CS, developing new methods of analyzing and working with CS data. In particular, we contributed several Bayesian approaches to the literature recently to increase the efficiency of CS data collection and optimize crowdsourcing.[68,69] We also address key issues in CS such as participant engagement and retention, data quality assurance and bias correction, as well as ethical considerations regarding data sharing and trust. We contribute to the discourse regarding CS and the development of free and open reference datasets based on contributions from citizens.[70]

In 2022, IIASA and partners officially launched the Citizen Science Global Partnership (CSGP). This network intends to mainstream CS and maximize the benefits of CS for global monitoring. NODES continues to obtain significant levels of CS-related external funding, recently launching several new CS initiatives. NODES leads the Urban ReLeaf Project (2023-2026) which addresses urgent urban climate issues while CROPS (2024-2027) aims to upscale CS.

Enriching Earth observation
NODES has a global reputation for enriching EO data with CS and crowdsourcing methods via its Geo-Wiki online platform. Numerous monitoring campaigns have been designed to collect a variety of new and novel datasets, which have allowed us to discover and track a variety of changes to the Earth's surface.[71,72] In particular, NODES has made significant research contributions in recent years to various aspects of global land use monitoring, contributing to the production of the EU's Copernicus global land service, and more recently to the European Space Agency's (ESA) WorldCover and WorldCereal Programs. These efforts provide critical baseline data for multiple EU policies including the new EU Deforestation Regulation on Deforestation-free products. As part of its longstanding relationship with ESA, IIASA is both contributing and hosting key global above ground vegetation validation datasets within the GEOTrees Network. This forms the in-situ component of the planned biomass satellite launch in 2024. Furthermore, as partner of CCI biomass, IIASA contributes its knowledge on global validation of bio-geophysical datasets.[73]
Part of a concerted effort to detect and measure the impact of various forms of commodity extraction across the globe, NODES has developed novel methods for commodity monitoring generating and compiling numerous open datasets (i.e. Mining, Oil Palm, Cocoa, Deforestation). A recent commentary raises concerns about the extensive, yet largely unmeasured, environmental and societal consequences of mining activities worldwide[74]. Since 2021, NODES has acquired substantial amounts of external funding to support its EO activities via national agencies, European funders, and global foundations. One of our recently awarded European projects, Open-Earth-Monitor, aims to build a FAIR-compliant cyberinfrastructure to accelerate the uptake of environmental information.

Exploiting the digital revolution

NODES is placing increasing emphasis on merging crowdsourcing techniques with AI methods, exploiting the power of computer vision[75–77]. We recently launched the Picture Pile Platform, a crowdsourcing tool, which allows for the rapid labeling of various forms of imagery, e.g., drone, street-level, satellite, etc. The resulting image libraries are then ideal input to machine learning applications and can address a multitude of SDG data gaps.[78] With the recent developments around big data and AI, we now have the capability to rapidly classify large amounts of data, and we are actively pursuing this in several research projects e.g. RapidAI4EO, EvoLand and Global Pasture Watch. The overarching goal is to establish the foundations for the next generation of ESA's Copernicus suite of products.

NODES has recently ventured into several novel areas of data science to explore the potential of such technologies to address data gaps in the SDGs. In particular, the ESA funded CAMALIOT project investigated the use of data received from navigation satellites via mobile phones to improve weather forecasting.[79] In addition, NODES, in partnership with the UNICEF recently launched the Donate Water App in the context of the YOMA project. Users of the app receive tokens for online purchases (using blockchain technology) in return for providing in-situ information on water quality, with over 5000 submissions to date across three African countries. In the process, young Africans gain valuable skills in the digital economy.

NODES has been awarded numerous external grants to support our efforts to exploit digital technologies. Within the GRANULAR project, we lead efforts to develop novel indicators of sustainable rural development across Europe to address the EU Rural Vision. These include e.g., web scraping, exploitation of social media, machine learning, CS, and others to address rural challenges e.g., accessibility, mobility, depopulation, employment and wellbeing. In 2024 NODES is hosting two international big data events; a Hackathon aimed at advanced data scientists who wish to exploit High Performance Computing (HPC), and; a global workshop aimed at practitioners who wish to derive policy impact from big EO data.

NODES Highlights of Scientific Output and Policy Impact

Adopting a citizen science approach to addressing the problem of plastic pollution in marine environments, Ghana has become the first country to **integrate this type of data on marine plastic litter into its official monitoring** and reporting processes. A new study presents this innovative approach on Ghana's citizen science journey and offers a pathway that can potentially be adopted in other countries.[61]

Accurate estimates and forecasts of crop area and yield play an important role in guiding policy decisions related to food security, especially in light of the growing impacts of climate change. IIASA researchers and colleagues[80] highlight the value of integrating remote sensing and data sharing for **timely agricultural information critical for food security** and sustainability planning. This work builds upon ESA's WorldCereal Project and related research activities.[81]

Almost one billion people are still living without access to reliable and affordable electricity, which in turn negatively affects health and welfare, and impedes sustainable development. A recent IIASA-led study[82] proposed a **novel method to estimate global economic wellbeing** using nighttime satellite images, building upon our previous research[83]. If applied over time, the method used in this study could provide opportunities to track wellbeing and progress toward SDG 1, helping to better inform energy and aid policy around the globe.

Exploiting the capabilities of crowdsourcing, NODES has produced the most **comprehensive free and open spatial dataset to date on the drivers of tropical forest loss**[64]. Armed with this knowledge, we then focused on global protected areas, documenting significant amounts of deforestation occurring in national parks, even with strict protection levels[66].

A recent commentary published in Nature[84], raises concerns about the extensive, yet largely unmeasured, environmental and societal consequences of mining activities worldwide and the subsequent policy impact. Global industrial and artisanal mining is having a significant detrimental effect in biodiverse regions of the globe[74]. With the global appetite for minerals expected to rise sharply in the coming decades, especially for clean energy technologies, comprehensive and transparent data on mining impacts is critical. Hence NODES has been **contributing to the most comprehensive spatial datasets openly available on global mining**[85,86].

2.2.2. SWOT analysis of NODES

Strengths	**Challenges**
• Reputation in CS and remote sensing well established • Very diverse set of skills in group – geography, forestry, mathematics, statistics, economics, social science • Increasingly close links to policy circles and UN • Invited to winning proposals, or able to form winning consortia • Strong development team with desktop and mobile apps and game experience – along with design capabilities	• Utilise our own derived datasets and tools to their maximum potential • Ensure our results are more visible (including data) • Place more emphasis on research/publishing as currently overstretched with projects/proposals • Update and enhance our CS platform Geo-Wiki (geo-wiki.org) • Improve communication means and channels to tackle broad scope of research being undertaken
Opportunities	**Threats**
• Working in an exciting, highly innovative research field with rapid changes • Collaboration potential is high among various research disciplines for our expertise • Funding for CS related research is plentiful and increasing • High demand for Geo-Wiki and our crowdsourcing/CS tools • Increasing need in AI and Computer Vision for classified Image libraries	• Increasingly research groups worldwide engage with CS hence competition is increasing (for funding, for partnerships, for impact) • Funder's priorities sometimes take us out of our niche area of expertise • Lack of inclusivity in CS is a growing problem

2.3. ASA's Exploratory Modeling of Human-natural Systems (EM)

2.3.1. Summary of achievement of goals and highlights

EM is an agile group of young researchers who came together from three different former programs of IIASA with the shared goal of developing cutting-edge systems-analytical methods, tools, and models to address the most pressing global sustainability challenges—much in the spirit of the overall ambition of the ASA program.

Empowering young researchers as principal investigators

- 14 projects (59%) in EM are led by female PIs or PIs with a PhD from less than ten years ago
- From 2022, 5 early- and mid-career EM scientists became first-time PIs generating 905.000 EUR

EM aspires to empower younger researchers. Over the last four years, several early- and mid-career scientists successfully took on leadership positions, acted as principal investigators, and led studies. In 2021-2024, more than half of all EM projects were led by researchers with a PhD from less than ten years ago. Several early- and mid-career EM scientists became first-time principal investigators acquiring third-party

funding from the Austrian Climate Research Programme (ACRP), the Anniversary Fund of the Austrian National Bank (OeNB), and a prestigious Marie Curie fellowship.

Contributing with new models to address evolving policy needs and societal challenges

EM published 10 papers and reports on the COVID-19 pandemic
- 6 using optimal control theory
- 3 use agent-based modelling
- 1 open-source dataset

The group's agility was demonstrated by its rapid response to the COVID-19 pandemic with diverse models (aligning with ASA Objective C). We examined lockdown policies using optimal control (EM Highlight 2).[10–12,87–89] By employing agent-based modeling (ABM), we conducted the first economic forecasts of the effects of lockdown policies early in the pandemic (EM Highlight 1).[90,91] Since then, we have developed this approach further in collaboration with the Bank of Canada to allow for more accurate projections for inflation, particularly during the current surge (EM Highlight 3).[52] In addition, we provided and maintained the widely used open-access IIASA COVID-19 tracker on daily regional COVID-19 statistics for European countries at the highest possible granular spatial resolution (NUTS3 sub-district level).[92]

Embracing new approaches and technologies to develop new models

EM embraces new approaches and leverages advancements in computing capabilities (ASA objective A). In collaboration with the University of Tokyo, we developed the first macroeconomic ABM for supercomputers,[15] allowing explicit representation of the behavior of each individual and firm in a country to study distributional impacts at an unprecedented level of granularity. This was showcased on Fugaku, which was the world's fastest supercomputer at the time, and we now routinely use the Vienna Scientific Cluster (VSC), Austria's largest supercomputer. To enable massively parallel computing without costly facilities, we utilize general-purpose computing on Graphics Processing Units (GPUs). GPUs aid in machine learning for projects like CMAF, which advances agricultural commodity price forecasting, and Plant-FATE, which applied this approach to eco-evolutionary vegetation modeling to predict species and regions vulnerable to climate change.

Advancing methods and models in all thematic areas according to the research plan

Overall, since 2021, EM has made substantial progress in advancing methods and models in all three thematic areas of the Research Plan, contributing to the major objective of ASA to innovate approaches and tools (ASA objective B). In the area of socioeconomic complexity (a), EM made a breakthrough in advancing the methodology of ABM and has developed the first ABM that is competitive with traditional models in macroeconomic forecasting—enabling previously unachievable applications of ABMs (EM Highlight 1).[91] This achievement built on the investment of the former ASA program and the Systemic Risk and Network Dynamics (SRND) cross-cutting project. In addition, several studies applied ABM to model complex dynamic feedback between different domains. For example, we used ABM to study how climate stress, financial constraints, and different financial instruments may affect rural-urban migration in smallholder farmer communities.[93,94] In another study, ABM was utilized in combination with micro-level data to model the effects of climate-induced supply-chain disturbances.[95]

EM advanced Earth systems models (thematic area b) by developing a new Bayesian-inferred carbon-climate model to explore linkages between socio-economic systems and the Earth system in a probabilistic framework that accounts for technological and socio-economic uncertainties. This novel model was first used to study mitigation pathways robust to physical uncertainty and economic modeling choices.[96] In addition, the development of the compact Earth system model OSCAR, with which we contributed to Working Group I of the IPCC's 6th assessment report and the annual Global Carbon Budget,[97–99] and participated in the first comprehensive intercomparison of reduced-complexity models (RCMs[7]), was continued.[40,49] The flexibility of the model was also used to investigate global interactions between climate, crop yields, and mitigation potential, discovering a potential tipping point in the climate system after which the yield of bioenergy crops might be reduced too much to effectively be used as a source of negative emissions, making it even harder to combat climate change.[41]

In the area of macro-level systems models (c), a multitude of stylized models was developed to provide high-level insight into novel challenges or examine new solution options in problems related to the transformation to sustainability, by modeling linkages between human and natural systems. For example, we used optimal control to examine freshly introduced COVID-19 lockdown policies (EM Highlight 2).[10–12,87–89] We created an innovative, collaborative modeling framework to create globally consistent national pathways for transforming food and land-use systems (EM Highlight 4).[100,101] We developed a new model consistent with IPCC scenarios to assess the impact of a novel carbon pricing instrument on achieving net negative emissions for implementing 1.5°C-scenarios (EM Highlight 5),[102,103] and we incorporated a fairness perspective into policy optimization models for sharing the burden of climate mitigation and adaptation.[104]

Highlights of EM scientific output and policy impact

- Developing an agent-based model for macroeconomic forecasting

We developed the first ABM that is competitive with traditional models for macroeconomic forecasting.[91] This model combines data from multiple sources to offer a detailed, dynamic representation of the economy, encompassing various sectors and actors. Its forecasting ability introduces novel applications previously unachievable with ABMs, such as predicting economic responses to unforeseen global events like financial crises and pandemics. The model's utility was first demonstrated during the COVID-19 pandemic, accurately projecting the economic impacts of lockdown measures in Austria.[90] Due to its proven effectiveness, the model has been adopted by numerous institutions and is now utilized in diverse applications.

- Optimal control theory to provide insights into pandemic response

We investigated whether lockdowns and vaccines are substitutes or complements during the interim from vaccine approval to widespread vaccination.[11] Using a dynamic optimization model that considers epidemiological and economic factors, we found that lockdown intensity should typically decrease as more people are vaccinated, reflecting conditions in developed countries. However, different strategies may be optimal depending on specific parameter values. Strategies that disregard previous infections perform nearly as well as those that consider them. Sometimes, minor increases in vaccine availability can significantly change the optimal approach, favoring longer, stricter lockdowns. This highlights the complex interplay between policy decisions, vaccine distribution, and public health outcomes.

- Using agent-based modeling to inform monetary policy of Canada

In collaboration with the Bank of Canada (BoC), we developed an ABM for monetary policy analysis. The model departs from rational expectations and introduces richer household and firm heterogeneity, marking an advancement in the toolkit of central banks.[52] The ABM allowed the BoC to have more accurate projections for inflation, particularly during the current surge. The BoC now routinely uses the model as part of their in-house core macro models, marking the first instance a major central bank has adopted an agent-based model to inform monetary policy. Its success has sparked interest from several other central banks, including the Bank of Italy, the Bank of Spain, and the Hungarian Central Bank, which are now adapting the model for their own use.

- Developing a collaborative modeling framework facilitating sustainability transformations

We created an innovative, collaborative modeling framework to create globally consistent national pathways for transforming food and land-use systems.[100,101] This framework allows local researchers to independently use national models to explore mid-century pathways, which are then integrated into globally consistent national pathways by the framework. Currently, over 200 researchers across 24 country teams utilize the framework. These teams are part of the Food, Agriculture, Biodiversity, Land-Use, and Energy (FABLE) Consortium, which operates under the Food and Land Use Coalition (FOLU), which aims to understand how countries can transition towards sustainable land-use and food systems.

- Operationalizing the net-negative carbon economy

We developed a new model consistent with IPCC scenarios to assess the impact of a novel carbon pricing instrument—Carbon Removal Obligations (CROs)—on achieving net negative emissions for implementing 1.5°C scenarios. By requiring emitters to cover the costs for the removal of previously emitted CO_2, our findings suggest that CROs could significantly mitigate risks related to net negative emissions, such as the risk of default by carbon debtors. This approach, involving charging interest on "carbon debt," offered a valuable contribution to the global climate policy discussion. It was presented to EU negotiators before the recent COP in Dubai and has now become a fundamental theme of the Climate Overshoot Commission.

2.3.2. SWOT analysis of EM

Strengths	**Challenges**
• Diverse expertise and knowledge to innovate in many topics and explore new models and methods • Flexibility and agility to react with new models to societal challenges, such as COVID-19 or the inflation surge • Embracing of new approaches and technologies, such as super and cloud computing • Large number of diverse external projects from multiple funding sources • Many young and first-time PIs giving staff room to develop and grow	• Expertise and focus of the RG is on exploration rather than on exploitation • Getting external funding for innovative approaches and basic research is difficult • Lack of stability with many smaller internal and externally funded projects • External funding is tied to deliverables, which makes it difficult to find time to collaborate, mentor, and write new proposals • Getting access to the latest technologies and software, such as cloud computing is difficult
Opportunities	**Threats**
• Maturing models developed in EM are ripe for exploitation (MacroABM, OSCAR, FABLE, etc) and could became future IIASA flagship models • Larger external projects could provide more stability and allow for more collaboration • More open-access publishing and open-source models could lead to more citations and higher visibility • Large suite of models of different complexities to react to the next big societal challenge	• Large percentage of funds comes from external funding • High fluctuation in funding is possible when relying on smaller, externally funded projects • Successful models can consume EM work (in exploitation) rather than continuing the exploration of new models and methods • Risk that in EM developed models get passed to other RGs and will be exploited there without adequate recognition

2.4. ASA's Systemic Risk and Resilience (SYRR)

2.4.1. Summary of achievement of goals and highlights

The SYRR group's mission is to analyse the increasingly systemic socio-ecological risks associated with global and local change, and with policy, practice and civil society co-generate options for building resilience. SYRR operationalised its mission by crafting four objectives (see below), which the team addressed with inter- and transdisciplinary science. Research outcomes have been targeted at understanding risk and resilience as well as informing and co-generating possible actions for policy, practice and the private sector with a focus on the most vulnerable. A strong focus has been on disaster risk, climate change, ecological risk, and increasingly human health (health impacts, pandemics). The research conducted has been highly collaborative within ASA and other IIASA groups as well as partners across the globe.

Further developing and strengthening the unique approach for addressing existential and systemic risk policy issues

SYRR, in close collaboration with other leading research institutions, policy and practice, developed guidance on systemic and multi-hazard risk[28, 105], on comprehensive risk management in development cooperation[106] and urban areas.[18] We experimented with the innovative physical climate storyline approach[107] to explore complex impact transmission pathways and unfoldings of event cascades under future climate conditions.[107] One key focus has been on understanding existential climate-related risk,[31] which is seeing increasing attention. Concepts of adaptation limits and social tipping points[108] provide inroads into understanding when risk in social systems becomes existential, for which we are setting up a global repository. We studied lessons from COVID-19,[109] which included the need for improved data to understand the contagion effect in complex systems as well as a lack of governance models for such systemic risk manifestation. Further applications of risk and resilience analysis to health (with SHAW) and food show the power of systems-oriented risk analysis.[110] Ongoing work has the group working with about 100 communities and regions across Europe in the CLIMAAX and P2R projects to innovate systemic risk and resilience analyses for impact.

Advancing & applying quantitative estimation methods to assess emerging systemic risks and disaster resilience

In collaboration with the ASA's NODES group, SYRR further advanced the widely used and currently only validated flood resilience measurement F/CRMC tool towards multi-hazard (heat, wildfire) resilience. Global work on validation shows the tool is valid and reliable,[7] community-led work by INGOs shows the usefulness in terms of addressing difficult and salient question, such as that of informing retreat and relocation hotpots, as done, e.g., for Bangladesh. We advanced the analysis of displacement risk under climate change, where we identified rising incidents as well as costs of displacement.[111] We further extended the focus of our fiscal risk assessment model CatSim[112] and related economic modelling to multi risk contexts (pandemics) as well as other risk aspects (with ASA's EM and CAT groups, and IIASA's EF and ECE programs).[113] We use multi-model approaches[114] including macroeconomic and agent-based[115] analysis to understand the distributional[116] consequences of disaster risk on households and the aggregate economy as we as evaluate policy, such as through insurance and social protection applications in a context of ambiguity or autonomous adaptation.[117] With supply chain and lifeline disruptions as well as system failure proliferating in socio-ecological systems exposed to today's polycrises modelling work using statistical processes, machine learning and big data[117] offers enhanced insight for better representing multiple lifeline disruptions,[118] understanding systemic risk from disaster and climate risk[119] as well as ecological collapse, such as in fishing populations.[120]

Developing and applying ecological network principles to the resilience in socio-ecological systems general focus

We developed novel socio-ecological resilience and network analytical methods and applied these to urban risk and resilience issues. Building on the concept of urban metabolism, jointly applied both input-output and ecological network analyses to study direct and indirect greenhouse gas emissions as well as energy and water footprints in comparative studies across major European, Chinese and Latin American cities.[32, 121] Using system dynamics modelling, SYRR researchers (with EM and others) studied the dynamics of socio-ecological systems and settlements affected by climate change, biodiversity loss and other risk drivers[121] using network analytical methods, we addressed methodological challenges related to the concepts of reciprocity in food webs and economic networks,[122] functional connectivity in dynamical systems process[123] and the use of efficient indicators for studying the robustness of populations in the context of habitat loss.[124] We will further proceed to study urban resilience in the context of low-carbon and inclusive development trajectories.

Further developing and applying methods to inform risk management and climate adaptation decision-making

For dealing with complex and dynamic climate-related risk, we develop evidence-based insight on adaptive risk management for global and EU policy applications including for the reform of

the EU Solidarity Fund.[125] We work on the triple resilience dividend decision-making approach, a novel and improved decision-support method for disaster and climate resilience, where current implementation has been found by ASA lead authorship in the IPCC to be inadequate as "small scale, fragmented and reactive."[48,126] In addition to standardly considered risk reduction benefits, this approach considers positive and negative externalities, such as unlocked socio-economic potential where risk is reduced, as well as co-benefits generated from risk reduction investment that also creates developmental gain (e.g., in health infrastructure). SYRR has been engaged strongly in creating evidence at community-scale,[127] nature-based solutions, water,[128] for equitable outcomes[129] and at macroeconomic scale.[130] To work towards solutions in the context of the climate and other multiple, connected polycrises, participatory modelling[19] is an essential starting point for SYRR to then proceed further in term of engaging in science for implementation, most notably through the work in the Flood/Climate Resilience Alliance, where we engaged with leading NGOs and the private sector for understanding and building resilience in vulnerable communities across the globe. In addition to the C/FRMC tool other boundary objects for co-generation developed in this Alliance include forensic post-disaster analysis[131] and a cross-cutting initiative on gender, inclusion and disability.[132] A key focus of the Climate Resilience Alliance underway is on resilience in multi-hazard context, for which we currently include storm, heat and drought risks into our toolbox. Lead authorship work for the IPCC[48] has revealed that in the climate crisis, incremental approaches are reaching their limits and the role of systemic change through transformation is seeing increasing attention. SYRR research has addressed knowledge gaps,[133] with POPJUS assessed concepts and framings,[134] the role of learning[135] and studied climate risk[136] and transformational resilience capacity[137] in hot-spot countries and systems, nature-based solutions[138] and wildfire[139] risk. Given limited evidence on transformation, a multi-author book with the Climate Resilience Alliance is providing concrete evidence of implementation by NGOs, policy and the private sector along various case studies and synthesis. Applications on ecological and pro-poor planning for disaster risk in urban spaces reflects the growing importance for considering the urban space as a risk generator, but also a resilience solution space.[140] SYRR (with input by POPJUS) researchers over the last few years strongly published and engaged with policy and practice to significantly contribute to the breakthrough in climate policy negotiations that led to the establishment of the Loss&Damage fund for supporting the most-vulnerable for coping with climate impacts and risks.[141]

SYRR Highlights of Scientific Output and Policy Impact

- Research that generated **guidance and modelling work on multi-hazard**[28] **and systemic risk**[105] has well responded to a strong need by policy and practice at local, national, and international scales to help better understand the multiple drivers of disaster and climate risk as well as understanding risk as increasingly dependent and leading to collapse as limits to 'adaptation' are being breached.[28, 108]
- The C/FRMC **resilience assessment** tool, co-generated in transdisciplinary collaboration with leading international INGOs and the private sector in the Flood Resilience Alliance (now Climate Resilience Alliance), has been further developed, validated and informed resilience building in more than 50 countries and 500 very vulnerable communities creating tangible impact for more than 3 million people across the globe.[7]
- **Innovative research on the tightly interlinked urban metabolism** using socio-ecological resilience and network analytical methods led to enhanced insight on understanding and shaping urban resilience interventions integrated with developmental transitions, such as resilience that supports circular economy applications in key cities across the world.[121]
- **Research on Loss&Damage** led to a climate policy breakthrough with the decision on a Loss&Damage fund for the most climate-vulnerable countries at COP27. Impact has been achieved through a first stocktake book on the issue with close to a million access items currently,[142] a policy forum in Science,[143] various other publications, including on finance,[141] quantification of needs and governance[144] as well as leading synthesis on this contested item in IPCC reports, as well as the lead in a Flood Resilience Alliance Flagship Report.[145] Policy

engagement also involved in a SYRR researcher being invited to negotiate this item for the EU.

- The concept of **triple resilience dividend decision-making** offers a novel way for **co-benefits-based decision-making** to sway decision-makers to further invest into disaster risk reduction and development jointly. We created evidence for various community-scale risk management implementation interventions,[127] nature-based solutions and water sector,[128] for distributional outcomes[129] and at macroeconomic scale.[130]

2.4.2. SWOT analysis of SYRR

Strengths	**Challenges**
• Strong standing in int'l risk research with long history and large network • Diverse, gender-balanced, young, and motivated international team, with expertise in natural and social sciences, engineering, economics, statistics and humanities • Rich methodological toolbox combining soft and hard systems analysis engenders capacity to truly tackle transdisciplinary problems • Demonstrated ability to go deep into the science-policy-practice space (work with practice locally, negotiate with policy globally) • Research reaching across scales covering studies at the local/community level with global insight • Proven ability to develop and maintain innovative partners along science-policy-practice interface • Integration of health (systems) research with risk and resilience agenda • Strong cooperation at IIASA (with all programs), leading and actively involved in Strategic Initiatives • Strong capacity to leverage funding from international public and private sector sources • Strong network incl. alumni (former YSSPers, post-docs) and guest scholars from diverse set of scientific backgrounds and nationalities • Consultative group leadership: transparency in communication and strong teamwork	• Finding balance between universal "big messaging" vs. reporting local nuance • Publishing on confidential practice and policy insights • High transaction costs involved in science-policy-practice work vs. focus on publications • Dependency on external funding and proposal writing efforts
Opportunities	**Threats**
• Increasing attention to policy and public to climate, disaster and other risk research in the wake of the climate crisis, complex risks and polycrises • Further linking at scale of systemic and existential risk research to global tipping points work • Further exploit capacity to involve IIASA researcher in transdisciplinary research issues for impact • Further harness networking and funding opportunities for IIASA researcher to connect to policy, practice and private sectors • Capacity to connect soft and hard systems analysis methods for advancing emergent systemic risk research field • Offering further open access models and data • Integrating AI in research agenda • Further making use of IIASA NMO network	• Trade-off between quick and "big messaging" vs. nuanced and slow insight relevant for policy and practice impact • Increasing confidentiality of practice and private sector data • Reduced/stagnant NMO funding • Increasingly competitive funding landscape • Impact of AI on evidence-based applied research

2.5. ASA's Cooperation and Transformative Governance (CAT)

2.5.1. Summary of achievement of goals and highlights

The ASA's Cooperation and Transformative Governance (CAT) group mission as stated in the IIASA 2021-2024 Research Plan has been **to analyse governance and decision-making processes under uncertainty, complexity, ambiguity, and volatility while incorporating systems thinking into strategic policy planning, addressing social dilemmas and wicked policy issues while applying interdisciplinary approach**.

CAT operationalised its mission by inter- and transdisciplinary science to support feasible, science-based, participatory, compromise-oriented public policy planning. The group conducts research on multiple strategic goals and priority directions when strategic goals followed by formulation of criteria which should be satisfied to achieve these goals, leading to identification of factors, policies, and actions. At the centre of its research is the decision-making process with multiple stakeholders and criteria, which reflect national development goals and are typical for various sectors. The focus of the research is on multiple viable factors that affect criteria directly or indirectly via other factors in interdependent or interconnected sectorial issues. Multiple strategic goals and priority directions when a strategic goal is an overall policy to be designed and priority direction is a specification of a strategic goal.

The CAT research group has as a goal the research on societal transformation driven by technological innovations and industrial transformations, such as energy transitions or digitalization, as well as environmental or health related crise.

To research the societal transformation CAT research group contributes to development of methodologies for participatory governance on managing social dilemmas and public wicked problems in the cause of societal transformations. This includes the development of methodologies on cooperation models, decision support systems and participatory modelling to research on existing and emerging governance challenges, and their complex structures and dynamic evolutions on such topics as health-related issues, climate change, societal transitions and digitalization.

Further developing and strengthening the unique approach to address multiple strategic goals and factors in cooperation and transformative governance
This work aligns with CAT's methodological ambition to advance the use of models to understand and support decision-making under volatility, uncertainty, complexity, and ambiguity. The methodology of addressing several strategic goals and multiple viable factors was significantly expended through research on how system maps, multi-criteria decision analysis, participatory scenarios, behavioral economics analysis and optimization models can facilitate a shared understanding of a problem's complexity, promote critical thinking, and identify potential leverage points. The further development of such participatory methodologies as foresight and multi-criteria decision analysis supports the CAT's goals to facilitate stakeholder dialogue on complex issues, bring parties in conflict to a shared understanding, and assist decision-making under deep uncertainty.

Advancing and applying quantitative and qualitative methods of behavioural economics and institutional analysis in governance research, including social factors, engagement and ownership of governance processes
In the field of behavioral economics the CAT group was developing and refining theoretical frameworks, alongside employing advanced statistical techniques such as Structural Equation Modeling (SEM), AMOS and SmartPLS to analyze complex relationships and validate theoretical constructs. The focus was on understanding the underlying mechanisms driving adaptation and mitigation behavior in various contexts, ranging from economic decision-making to social dilemmas and management of common goods including individuals' willingness to engage in climate change mitigation, and adaptation policies and the effectiveness of different incentive structures in promoting environmentally sustainable behavior[146] [147].

Advancing and applying multi-criteria optimization for research on complex governance issues and cooperation governance
Further on, the essential for risk governance methodology of multi-criteria decision analysis (MCDA) was developed and expended. The CAT research group developed the methodology which facilitates the use of automatically generated weights (often called surrogate weights) to represent user information[148]. This is world-leading methodology research in this area[149].

Advancing and applying methodology of causal loop diagramming for governance of transition and transformation processes as well as governance of common goods
CAT group contributed to development of methodology of systems mapping, also known as causal loop diagramming (CLD), is a key systems thinking tool used to visualize the components of a complex system and the interconnections between them. It enables building a shared understanding of the system and identifying its key drivers and leverage points. This methodology was applied for case studies of COVID-19 pandemic to investigate the impact of the COVID-19 pandemic on a broader human–society–environment system [150].

Advancing and applying methodology of systems maps
The methodology of systems map of the national well-being system and scenario planning as a foresight approach was further developed to explore plausible future developments of a complex system under high uncertainty. CAT group further developed this methodology and applied it to investigate futures of the Arctic, a region undergoing rapid changes. The scenarios were co-created with experts from various countries in a participatory process[151].

Advancing and applying methodology of governance of systemic risks and nexus issues
CAT group contributed to the development of a methodology to analyse the dynamic and interactive conditions of natural disaster risks and possible risks of compound chain events (systemic risks) to make better predictions regarding possible future risk exposure and vulnerability. Namely, CAT group contributed to the development of "Integrated catastrophe modeling and management framework" by linking catastrophe risk models (CRM) with stochastic optimization (STO) techniques for the design of optimal and robust mitigation and adaptation strategies for risks of all kinds. Further contribution was provided to develop methodology for analysis of policies in interdependent systems of food-energy-water-environmental (FEWE) sectors which require integrated coherent planning and coordinated policies for sustainable development and security nexus. Such an integrated Energy-Food-Water-Environment (EFWE) decision support system (DSS) enables to develop robust systemic regulations for disintegrated distributed EFWE systems in the presence of risks and uncertainties of various kinds relying on robust distributed models' linkage and optimization methods[152].

Developing and applying innovative methods in governance such as usage of artificial intelligence tools
Social Intelligence Mining (SIM) is the artificial intelligence tool developed by CAT. This tool excels in parsing the vast landscape of digital discourse, offering insights into public sentiment with unprecedented precision and depth. It harnesses the power of cutting-edge technologies including advanced statistical methods, AI, machine learning, and deep learning. Key applications include trend identification, crisis management, influencer marketing, and beyond, proving essential for engaging with audiences and navigating the digital zeitgeist. The SIM tool contributes greatly to the topic of risk governance with the following research capacities: enhanced predictive analytics to foresee trends and societal shifts before they enter the mainstream, more nuanced sentiment analysis capable of understanding complex emotions and sarcasm, providing a deeper understanding of public opinion, greater integration with other data sources for a holistic view of societal trends and improved user interfaces and visualization tools that make data accessible to a wider range of users, from experts to novices[153,154].

Highlights of scientific output and policy impact

- CAT researchers developed a **cloud-based online service platform** that offers support in analyzing and evaluating dynamic risk scenarios and systemic risks caused by multi-hazard

disasters. The perform is based on in-depth assessments of the interactions between hazards and their resulting impacts in various sectors. In addition, it allows for analysis of the current risk situation and study how alternative future scenarios could change multi-hazard impact chains[155].

- CAT researchers introduced a **Social Media Intelligence Mining Tool** which allows to redefine our understanding of public sentiment and discourse across digital landscapes. The tool is designed to revolutionize the extraction, analysis, and reporting of intelligence information from a myriad of social media and web platforms, including X (formerly Twitter), Google, and news outlets. It leverages the latest technological advancements, it seamlessly integrates advanced statistical techniques, web and text mining, artificial intelligence (AI), machine learning, and deep learning, among others[154].
- CAT researchers developed methodology for **intelligent risk analysis and multi-criteria assessment** of the effectiveness of COVID-19 counteraction using a combined approach to identifying the dynamics model. The methodology's focus is on the development of metrics and indicators to assess different scenarios and their impact on changing hazards, as well as the potential impact of different scenarios on the hazards posed by different models[156].
- CAT researchers contributed to the UK Research and Innovation (UKRI)/Natural Environment Research Council (NERC)'s Constructing a Digital Environment Program which is an expert network of leading influencer-practitioners, thought-leaders, and scientific and technical authorities, whose work aims to identify best practices in the digital environment and to influence UK environmental policy thinking, drawing on expertise in the methodologies and tools for assessing, analyzing, monitoring, and forecasting the state of the natural environment.
- CAT researchers contributed to the work of the United Nations Environment Programme's (UNEP) Foresight Expert Panel established in cooperation with the International Science Council (ISC). UNEP has partnered with the ISC to advance science-based strategic foresight and futures thinking to enable better preparedness and proactive engagement with future challenges, and to inform and guide decisions for the benefit of the global environment. The Foresight Expert Panel was established to aid in processes to identify and evaluate emerging issues and signals of change, and to guide and oversee this critical work.

References

The references are available in this link.

2.5.2. SWOT analysis of CAT

Strengths	**Challenges**
• Multidisciplinary expertise, for example, in behavioral economics, multi-criteria optimization, participatory modelling and scenario development • Diversification of available skills • Strong methodological basis in research on governance • Availability of models and tools developed within the ASA program and CAT group • Research combining applied and methodological focus • Experience in stakeholders' engagement • Experience in science to policy • Connection to science and policy discourses for dissemination of results • A geographically diverse, gender-balanced motivated international team with expertise in natural and social sciences, engineering, economics, statistics and humanities • Combination of soft and hard systems analysis engenders capacity to truly tackle transdisciplinary problems	• Dependency on external funding and proposal writing efforts
Opportunities	**Threats**
• Potentials of AI in data collection • Societal transition and transformation processes caused by technological innovations, geopolitical and other challenges highlighting the growing importance of theory of changes • Ongoing transition processes such as energy transition, digital transition and others and potentials for research • Networking and collaborative opportunities provided by digital solutions • Potentials for high impact research due to involvement into research activities of stakeholders from practice • Growing opportunities in science to policy domain	• Accessibility of data from social media and internet platforms such as recent developments with X (former Twitter) • Stakeholders fatigue in participatory research • Increasingly competitive funding landscape • Too high work load on partners from test and case studies • Ethical issues with usage of AI

The complete report of the Advancing Systems Analysis Program is available at the following link: ASA Self-assessment report 2021-2024.

3. Program: Biodiversity and Natural Resources (BNR)

BNR mission is to provide insights and knowledge that promote global and regional systemic transformations toward sustainable integrated biosphere management.

The Program consists of four Research Groups working together towards the BNR mission: **Agriculture, Forestry and Ecosystem Services (AFE)** developing biophysical process-based models for design of resilient and sustainable management strategies in agriculture and forestry, incl. optimal spatial allocation relying on the landscape approach; **Water Security (WAT)** relying on hydrological and hydro-economic models with participatory methods to inform solution-oriented policy assessments of complex water challenges; **Biodiversity, Ecology and Conservation (BEC)** developing biodiversity and protected areas design models to mainstream biodiversity topics into integrated policy assessments; and **Integrated Biosphere Futures (IBF)** combining economic modeling with modeling of ecosystem integrity, land use needs and secure water services in an integrated framework to satisfy human needs while ensuring the sustainable use of natural resources.

BNR relies on its 104 FTE (Full Time Equivalents) employees, composed of 97 FTE scientific staff, including software developers, and 6.75 FTE operational staff, of more than 30 nationalities. The Program capacity is further increased through the cohort of 81 Guest researchers. These numbers are the result of a steady growth since 2021, scientific staff and operational staff increased by 25% FTEs each, and the associated Guest researchers by 11%. The Program regularly hosts large number of PhD students and postdoctoral fellows and promotes the professional growth of its researchers – 18 promotions to Senior Research Scholar and a promotion to Principal Research Scholar.

Next to the dynamic and highly qualified staff, the second pillar of BNR are its world-wide recognized large scale applied models, such as the Global Agro-Ecological Zone model – GAEZ, the global economic model of the agricultural and forest sectors – GLOBIOM, or the global forest management model – G4Mm, and the crop growth model – EPIC-IIASA, as well as the more recent additions, such as the hydrological model – CWatM, the hydro-economic model – ECHO, or the most recent development, the integrated species distribution model for biodiversity assessments – iBIS. In the research period 2021-2024, BNR was striving to continuously develop these models and to bring them into a consistent, modular, and open integrated modeling framework (iBIOM), the progress towards this goal is presented in detail below. The quantitative modeling suite is complemented by state-of-the-art participatory approaches for co-development of future scenarios and co-identification of solution options.

3.1. Overall Program Achievements 2021-2024

3.1.1. Research and internal collaboration

Spinning the virtuous circle of academic success

The ultimate objective of BNR is to generate positive societal impact and therefore it devotes substantial efforts to directly engaging with policy processes. This ties BNR research to real-world problems driving genuine innovation rather than moving within established paradigms, and promotes high-impact scientific publications. Policy relevance together with research excellence are attracting funders both from the policy arena and from academia, which in turn are spinning the virtuous circle of BNR success (Figure 3.1).

BNR delivers policy support across different geographical scales and topics. Its policy impact assessments directly support national and regional (EU) governments in designing policy for land-based climate mitigation, sustainable water management, or biodiversity conservation. However, BNR engages also in transboundary issues (e.g., in transboundary river basins) and

sub-national policies. Finally, BNR modeling and expertise contribute to international regulatory processes as well as international assessments, such as those by IPCC, IPBES or IRP.

Complementarity rather than competition between policy support and scientific innovation, BNR researchers published 450 peer-reviewed papers (an average of ~5 per employee, based on an average of 92,5 employees 2021-2024), of which 393 were published in Scopus-listed journals. Of these 393 publications, 18,6% were in the top 1% journals (based on impact factor) and 67,7% were in the top 10% journals. 68 articles published in the Science, Nature, PNAS and related journals. In terms of citations, these 450 papers were cited a total of 8.544 times (average of 19 citations per paper). 8.510 of these citations were from contributions to Scopus-listed journals, of which 42,4% were from papers in the top 1% journals and 92.4% were from papers in the top 10% journals. BNR researchers received also various awards recognizing their scientific excellence: 2 Clarivate Highly Cited Researchers, the rank 6 on the Reuters Hot List, Frontiers Planet Prize 2024 National Champion for Austria, and Early Career Conservation Scientist Award.

Finally, closing the virtuous circle – over the research period 2021-2024, BNR was involved in 161 externally funded projects, and the external funding represented about 76% of the Program resources. Part of the BNR funding is provided directly by the policy clients, or their funders, including World Bank or FAO, the largest amount of BNR funding, however, comes from academic research funders, and often in the form of large-scale collaborative research projects, where BNR acts as a coordinator of currently four projects, or as a partner. The external funding also generates about EUR 1 million in overheads contributing to the general IIASA operations.

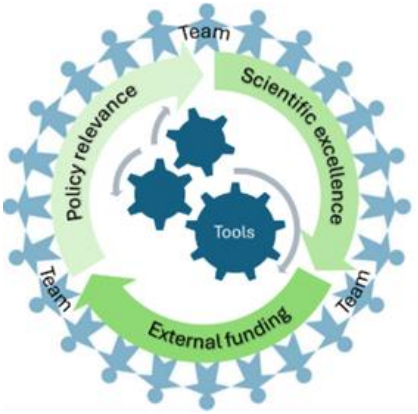


Figure 3-1. BNR virtuous circle of academic success

Progress towards the 2021-2024 BNR Goals

Biodiversity research has existed at IIASA prior to the launch of the 2021-2030 research strategy, but never before it had a research program and research groups focused on applied ecology and conservation. One of the 2021-2024 BNR goals is to **comprehensively respond to the major gaps and fully exploit the potential in biodiversity research within integrated systems analysis**. In other words, to fully exploit the potential in biodiversity research within integrated system analysis, address key knowledge gaps and inform global and regional policy assessments.

On the research side, the program has made incredible strides towards this goal, with 26 projects in the period 2021-2023 that included biodiversity research. Thirteen of these projects involved the newly established Biodiversity Ecology and Conservation (BEC) group, thereby contributing to develop and harness IIASA's internal capacity on applied ecological modelling. These projects involved four research programs (ASA, BNR, POPJUS, SI): bringing ecological

knowledge and addressing biodiversity conservation policies in the context of agriculture (Brightspace), forestry (ForestNavigator, BioConsent), climate change policies (BIOCLIMA), economics (ACCREU), equity and justice (FairStream), water management (FairStream, INSPIRE), earth observations and citizen science (Global Foodscapes, OEMC, NatureMap), land system science (LAMASUS, Global Foodscapes), and earth system science (RESIST).

BNR staff co-authored 108 publications, in applied ecology and conservation from January 2021 to March 2024, 24 of these were led by BNR scientists. The integrative nature of these analyses, was not only pioneering from a scientific perspective, but also enabled the identification of nature-positive pathways that inspired goals and targets of the Kunming-Montreal Global Biodiversity Framework (GBF) and allowed to assess the biodiversity implications of the 2040 climate targets.

Another BNR goal was to **establish IIASA as the first international community hub for integrated biosphere research** through **development of an integrated assessment and modeling framework of Earth's biodiversity and natural resources** relying on **innovative tools development to facilitate community-driven efforts for sharing knowledge within the modeling systems**. Although this goal was extremely ambitious within the given time frame, BNR laid solid foundations to achieve it in the medium term. The main two pillars are the Integrated Biosphere management Model (iBIOM) and an innovative underlying IT platform – Accelerator, see Figure 3-2.

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. 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-IIASA), forestry (G4M), wildfires (FLAM), and hydrology (CWatM), hydroeconomics (ECHO), and water pollution (MARINA and SWAT).

The biophysical information on productivity, water, and nitrogen impacts is explicitly considered in the 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) and dynamic vegetation changes (PlantFATE). 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 for automated data assimilation procedures, 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.

Main achievements to date:

- iBIOM kernel composed of GLOBIOM, G4Mm and downscalr has been consolidated through scripted workflows allowing automatized sequential execution of the models on the BNR computational server. The fully operational component is now routinely used for project delivery, for instance to analyze synergies and trade-offs between climate and biodiversity goals in Asia, funded by the Ministry of Environment in Japan. GLOBIOM-G4Mm-downscalr represent also the land use component of the IIASA integrated assessment modeling framework MESSAGEix-GLOBIOM, this development thus opens new opportunities for collaboration with the ECE Program.
- In the context of climate change impacts and adaptation, interfaces were developed also between the crop growth model EPIC-IIASA, the hydrological model CWatM, and GLOBIOM, to analyse the impacts of the CMIP6 scenarios and to provide corresponding land use and

management outputs to the ISI-MIP3b project. This coupling has not been fully automatized yet.

- GLOBIOM, G4Mm and downacalr were interfaced also with the biodiversity model ibis.iSDM, and this cluster was used in the BIOCLIMA project to assess the synergies and trade-offs between EU climate and biodiversity conservation and restoration policies to support European Commission. Full integration into iBIOM workflows is envisaged for the next phase of the project.
- 13 newly funded cross-group projects involving at least two, and sometimes all four BNR Research Groups and supporting further integration across the iBIOM candidate models have been started since 2021. Typically four years long, these projects will allow for another quantum leap in iBIOM development.

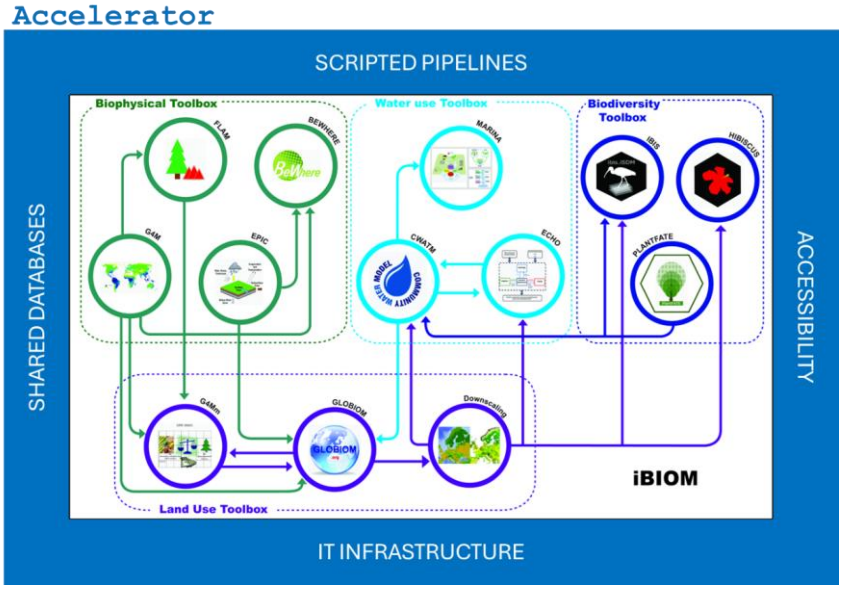


Figure 3-2 Selected examples of BNR policy impact work

Accelerator

So far, iBIOM builds on BNR internal models. However, its IT platform Accelerator is designed to host iBIOM 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 cyberinfrastructure will thus contribute to boosting the modeling capacity of the global community to support decision-makers in development of sustainable biosphere futures.

Accelerator has four main components, namely the Data Repository, Model Repository, Computing module and Data and Scenario Explorer. These components will host the data, models, and source codes, as well as workflows for data processing and model deployment. This platform will allow BNR researchers and external researchers to interoperate shared data and models, to reduce modelling cycles, and to increase the outreach through visualisation of spatially explicit data and pathways. For more details, see the Accelerator concept note published in the context of the ForestNavigator project, where the ForestNavigator Portal is presented as one particular application of the Accelerator.

Accelerator implementation started only in 2023 when the suitable software engineer was hired. However, remarkable progress was already achieved.

- External funding approaching 1 million euros has been generated through externally funded projects – ACT4CAP27, BrightSpace, ForestNavigator and LAMASUS. These projects provide not only funding but also useful use cases involving a variety of non-IIASA stakeholders from modelers interested in contributing to iBIOM up to to the general public that is expecting user-friendly dashboards.
- Data repository has been deployed and successfully stress-tested with external dataflows of multiple terabytes. Data in a data repository can be validated against the user defined rules which makes the dataset features consistent and comparable against other similar datasets. Data access to the public or within the project team can be controlled.
- Availability of several in built and custom data visualization charts and graphs
- Scenario explorer, with several built-in custom data visualization charts and graphs, is operational and used by researchers within the BrightSpace and LAMASUS projects.
- Highly modular computation module has been developed with the capacity of defining the job graph taking parallelism into account and can be dispatched using http protocol. Compute module status and logs can be monitored over http. Computing module is ready for testing
- Two powerful computational servers totaling 384 cores were acquired to allow for intensive internal and external testing.

With these innovative and integrative modeling initiatives, BNR 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.

Another BNR goal was to **lead the integration of biophysical-economic modeling with governance**. Many water management decisions, such as the adoption of more effective irrigation techniques or changing crop types, are made at the farm level by a heterogeneous farmer population. While these decisions are usually advantageous for an individual farmer or their community, aggregate effects of those decisions can have large effects downstream. Similarly, decisions made by other stakeholders, such as governments, often have basin-wide effects and affect each farmer differently.

To fully comprehend how the human–natural water system evolves over time and space and to explore which interventions are suitable to reduce water stress, it is important to consider human behaviour and feedbacks to the hydrological system simultaneously at the local household and large basin scales. Thus, BNR researchers developed the Geographical, Environmental, and Behavioural (GEB) model, a coupled agent-based hydrological model. GEB enables simulating the behaviour and daily bidirectional interaction of more than 10 million individual farm households with the hydrological system on a personal laptop. GEB is dynamically linked with CWatM at a 1km resolution.

The GEB model is currently being used in the SI project fairSTREAM. In this context, the BEC eco-evolutionary plant model PlantFATE uses GEB land-use forcing and CWatM water availability information and returns soil evaporation and plant transpiration, improving the realism of the water cycle simulation.

BNR researchers have also advanced the macro-economic model DYNAMMICS for assessment of disaster risk reduction (DRR) policies under multiple hazards. DYNAMMICS can be used to analyze and compare various potential policies in terms of their economic effects. The decomposition of these effects into multiple benefits helps policy makers and other stakeholders better understand the ex-ante and ex-post advantages of DRR investments. DYNAMMICS has been used for coastal hazard assessment under climate change in the small island economies of Bahamas and Barbados, evaluating the interaction of disaster risk reduction investment options including nature-based solutions and risk financing options, advancing the analytical frontiers on the economic assessment of climate extremes.

As extensively documented in section below, and indirectly throughout the report, BNR successfully strengthened its international leadership in applied research of Earth's biosphere management for global and regional policy development. However, as part of this goal, BNR also intended to launch a new flagship product, the Global Biosphere Outlook, relying on a to be built stakeholder community, and this specific goal has not been reached yet although the first necessary steps were made, including i) substantial funding has been raised for establishment of iBIOM and the work on iBIOM advances, ii) progress has been made also in Accelerator implementation, which will be the backbone of the largely web-based Outlook, iii) template has been developed to gather relevant variables from the iBIOM modeling suit in a harmonized way, iv) baseline and selected policy scenarios were calibrated and validated in the context of ongoing projects, incl. BrightSpace, LAMASUS, and the IEA World Energy Outlook, v) a new generation of scenario thinking has been proposed, and vi) a stakeholder platform bringing together large group of policy makers and modelers will have its first meeting as the Forest Policy Modeling Forum in the framework of the ForestNavigator project in September 2024.

WAT modeling tools at BNR took advantage of **advances in Earth Observations (EO), big data and AI** to improve water resource availability and demand assessment. Several EO products are used to evaluate our model simulations. Changes in total water storage simulated with the Community Water Model (CWatM) globally and in different case studies are compared to those derived from GRACE (Gravity Recovery and Climate Experiment) and change in evapotranspiration are compared to those derived from MODIS (Moderate Resolution Imaging Spectroradiometer). For our large-scale water quality modelling, we are utilizing global EO products to evaluate our model simulations, specifically focusing on sediment and nutrient loadings into lakes and coastal waters. As a proof of concept, we tested this approach in Lake Tana, Ethiopia. We used EO lake turbidity data from the Copernicus Global Land Service (CGLS) to evaluate the simulated seasonal and multiyear trends of river sediment loadings into Lake Tana. Our results demonstrated strong positive correlations between the simulated sediment load from inflow rivers and EO lake turbidity at most river inlets which highlighted the potential of EO turbidity products in characterizing the temporal and spatial patterns of sediment loadings, particularly in data-scarce regions, and contribute to a better understanding of water quality dynamics. In collaboration with the EO workstream within the World Water Quality Alliance (WWQA) and several external partners, we are contributing to the development of a global Earth Observation-based indicator for SDG 6.3.2, which measures the "Proportion of bodies of water with good ambient water quality". Utilizing free and open-source satellite data, we are piloting this indicator with Lake Tanganyika and Lake Kivu in cooperation with local stakeholders.

WAT has used a machine learning algorithm to quantify sector-specific drought impacts in the Western Balkan and Eastern Europe region under future climate change scenarios. The assessment followed a risk factor approach, combining several proxy indicators of hazard, exposure and vulnerability. The outcomes of this assessment have completed the recently published European Drought Risk Atlas and supported the development of some of the World Bank Group Country Climate Development reports. Another study analysed streamflow variations as signatures of anthropogenic drivers. It combined global data spanning multiple decades from 5,163 catchments with variables like precipitation, evapotranspiration, water use, and damming, applying machine learning for trend analysis. This approach helps identify archetypal flow regime change classes, linking human activities and climate variables to changes in streamflow, providing insights for better water resource management and mitigation strategies. As part of the SOS-Water project, an effort to derive a dynamic crop coefficient (Kc) for hydrological modelling that relies on a comprehensive range of spatial datasets is ongoing. These data include daily historical meteorological data, such as temperature, wind speed, relative humidity, incoming radiation, and precipitation. Meteorological data are complemented by historical evapotranspiration (ET) data from various sources accessed through Google Earth Engine. The aim is to find the relationships between meteorological variables, ET and Kc using machine learning algorithms.

Last but not least, BNR goal was **promoting IIASA-wide collaborations.** Within the BNR Program, the Research Groups collaborated on 24 externally funded projects, and while this number represents only 15% of all BNR projects, the accumulated budgets of these 24 projects represent 36% of the total BNR externally funded budget (€ 12,5 million vs. a total of € 34,8 million). The total number is thus similar to the collaborative projects with Research Groups outside of BNR, 22 externally funded projects. However, these 22 projects together had a combined IIASA-budget of € 10,4 million (divided over more than just the BNR-groups), of which € 3,8 million was BNR-budget. With regards to Strategic Initiative, BNR is involved in 3 of the 4 projects funded so far and is leading one of them (RESIST). BNR co-authored 119 scientific articles with other IIASA Programs which is more than five times more than the number of publications across Research Groups within BNR, which were on 22. The cross Program collaborations often evolve around cross-model linkages such as the MESSAGEix-GLOBIOM framework or the joint policy impact assessments, such as those for the European Commission.

3.1.2. Policy Impact and external networks

While scientific innovation is at the core of BNR activities, the ultimate objective is societal impact. The Program thus engages in related activities along several dimensions: i) direct participation in regional and international regulatory processes, ii) exploratory studies for national and regional authorities, as well as international organizations, iii) participation in international assessments, and iv) support to the private sector.

Direct policy support to National/Regional/International regulatory processes.

BNR (IBF) continued to support the European Commission in preparation of key policy and legislative documents related to land-based climate change mitigation policies. The highlight of 2021 was the legislative package for implementation of the European Green Deal, the so-called 'Fit for 55 package', where IBF modeling contributed to the Impact assessment, similarly as to the newly developed EU Forest Strategy 2030. IBF models have also participated in quantification of the EU Reference Scenario 2020: energy, transport and GHG emissions: trends to 2050, and the Reference scenario for EU associate countries. Later, the GLOBIOM/G4M models have underpinned the development of the 2030 Climate Target Plan titled Stepping Up Europe's 2030 Climate Ambition. Most recently, the GLOBIOM/G4M modelling framework was used in an extensive Impact Assessment of the EU 2040 Climate target by EC DG CLIMA, including a biodiversity impacts section that relied on developments done in the BIOCLIMA project.

BNR also provides modelling capacities to Transportation and Climate Division (Office of Transportation and Air Quality) of the U.S. Environmental Protection Agency for the estimation and uncertainty analysis of induced land use change (ILUC) effects of U.S. road biofuels. Based on scenario simulations conducted by BNR, the U.S. EPA announced Final Renewable Fuels Standards Rule for 2023, 2024, and 2025 (link) on June 21, 2023 (IIASA news). The rule establishes biofuel volume requirements and associated percentage standards in view of steady growth of biofuel use in the US's fuel supply and aims to ensure a sustainable and environmentally friendly energy future. IIASA has a longstanding partnership with the EPA, having previously utilized GLOBIOM for similar assessments. The institute maintains an ongoing contract with the EPA to assess the implications of US biofuel policies as part of its commitment to international collaboration and employing systems analysis to address issues of global concern. BNR contributed also to the Greenhouse Gas Mitigation Potential in the U.S. Forestry and Agriculture Sector by the U.S. EPA.

At the international level, BNR (IBF) has continued to support the Carbon Offsetting and the Reduction Scheme for International Aviation (CORSIA), by providing estimates on the Land Use Change impacts of feedstocks for sustainable aviation biofuel production based on the GLOBIOM model, through the successive cycles of Committee on Aviation Environmental Protection (CAEP) for International Civil Aviation Organization (ICAO). The aviation sector has grown at a significant pace in recent years, and despite improvements in aircraft efficiency, the sector's impact on climate change is a growing concern. To address this concern, the International Civil Aviation Organization (ICAO) established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) to help reduce aviation greenhouse gas (GHG) emissions. To estimate ILUC emissions for aviation biofuels, noticing the considerable uncertainty in ILUC simulation results, two different economic models, well-established on this topic, were used: GTAP-BIO (Purdue University) and GLOBIOM (IIASA) as documented in the ICAO Environmental Report 2022 and a related scientific paper. The 41st ICAO Assembly adopted a Long-term global aspirational goal (LTAG) for international aviation of net-zero carbon emissions by 2050.

Finally, BEC and IBF groups provided substantial input to the final steps of the negotiations through a range of policy briefs and papers that were directed at the parties to the Convention on Biological Diversity (CBD) who agreed in December 2022 on a landmark multilateral environmental agreement, the Kunming-Montreal Global Biodiversity Framework (GBF). The Kunming-Montreal Global Biodiversity Framework refers explicitly to IIASA-BNR co-authored work in sections related to the theory of change, as well as in the context of Goals A and B and Targets 1, 2, 3 (on resource management planning, protection and restoration) as well as targets addressing sustainable production and consumption (10, 16).

Figure 3-3. Selected examples of BNR policy impact work

Country and regional policy support

BNR is extensively supporting decision makers in Africa. WAT received funding from the Austrian Development Cooperation for the implementation of a research for development project titled 'Accelerating transition towards resilient water and food systems in East Africa. Scaling out resilient water and agricultural systems (scaleWAYS)'. The project was implemented jointly by IIASA, the Lake Victoria Basin Commission (LVBC) and the International Crops Research Institute for Semi-Arid Tropics (ICRISAT). Through LVBC, member countries in the Lake Victoria Basin covering Burundi, Kenya, Rwanda, Tanzania, and Uganda have been involved in the research project while local universities and other research entities in the region were encouraged to

contribute by carrying out specific research activities. In the same region, the SWAQ-Uganda project funded by the Austrian Development Cooperation investigates sustainable water quality management through modeling and stakeholders' engagement to support Uganda's development ambitions.

Within an FAO initiative, a pool of international research institutions, including BNR (IBF), is conducting innovative modelling and analyses supporting Uganda to translate its national priorities for food systems transformation into concrete policies and actions.

BNR was also supporting the Government of Gambia in the framework of the FACE-Africa project, which looked into the issues of climate impacts, food insecurity, poverty, malnutrition, and its health-related effects, and co-developed scenarios to inform sustainable land-use pathways.

In Asia, WAT conducted a National Agro-Ecological Zones assessment (NAEZ) for Afghanistan which assessed the quality and availability of land resources and identified crop cultivation potentials for current and future agroclimatic conditions. The large database from the NAEZ Afghanistan has been made available via the LRIMS data portal and published as an Agro-Ecological Zones Atlas together with FAO. To support food systems transformation in Indonesia, FAO also coordinated a food systems modelling project involving IFPRI, IIASA, IISD, and Christian-Albrechts-University of Kiel, to inform the Government of Indonesia's medium- and long-term development planning by identifying technically sound and politically feasible policy interventions to achieve multiple policy objectives related to food systems transformation.

In Europe, the collaboration with the European Commission extends beyond the pure regulatory processes presented above providing model-based assessments for non-EU countries, including Energy Community countries (Albania, Bosnia-Herzegovina, Kosovo, Montenegro, North-Macedonia, Serbia, Ukraine, Georgia, Moldova), and broader topics. Thus, the interdisciplinary BIOCLIMA project led by BNR, in collaboration with UNEP-WCMC and EuroCARE, expands on the established climate mitigation policy impact assessment to also consider the EU Biodiversity Strategy the Farm 2 Fork Strategy, and provides insights into synergies and trade-offs between climate mitigation, biodiversity conservation and restoration, and sustainable food system.

Members of the BEC group were also invited to coordinate scientific input into the ongoing series of Biogeographical Seminars organized by the Expert Group on the EU Nature Directives including staff of the European Commission and delegations of national authorities responsible for implementing the directives from each Member States.

Moreover, the World Bank commissioned a project led by WAT to develop the so-called One-Water Methodology, which is a methodological framework for rapid assessment of water security, smart planning and development of practical recommendations at country and regional levels. In this context, WAT prepared deep dive assessment reports following the developed methodological framework for several countries in the Danube basin for informing investments and policies to enhance water security.

Finally, WAT worked also with the Inter-American Development Bank (IDB) to advise on the optimal disaster risk reduction and risk transfer investment in Bahamas and Barbados. In Bahamas in particular, the macro-economic modeling framework DYNAMMICS was used by the IDB to advise the incoming presidency on the need for proactive coastal risk assessment under climate change.

Contribution to international reports/assessments

BNR extensively supported IPCC work on the impactful 6th Assessment Report (AR6) on land and water related issues across the three Working Groups (WG) as Lead authors (1) and Contributing authors (5). Within WG1, The Physical Science Basis, contributions included Chapter 3: Human influence on the climate system, and Chapter 11: Weather and climate extreme events. Within

WG2, Impacts, Adaptation and Vulnerability, WAT contributed to evaluating recent efforts in assessing the feasibility and impact of different water adaptation and mitigation measures across Europe in Chapter 13: Impacts, Vulnerability and Adaptation in Europe. WAT further contributed to Chapter 4: Water by highlighting changes and uncertainties in projected water scarcity. In WG3, Mitigation of Climate Change, IBF contributed to Chapter 7: Agriculture, Forestry and Other Land Uses (AFOLU), and Annex III: Scenarios and Modelling Methods. In this context, it is worth mentioning that BNR scientists participated also in the Austrian Panel on Climate Change (APCC) and contributed particularly to the APCC Special Report: Landnutzung und Klimawandel in Österreich.

BEC and IBF have been taking leading roles in the IPBES NatureFutures task force and the IPBES Nexus assessment, with one lead author and one fellow. Both groups were also involved in the GEOBON, bioDISCOVERY and Future Earth joint working-group on post-2020 Global Biodiversity Framework. This led to the production of scientific papers, a report and several policy briefs synthesizing recent scientific evidence on the link between action targets and biodiversity outcomes as featured in the draft of the post-2020 Global Biodiversity Framework, submitted to the CBD as a information document (see also section 7) .IBF has participated in two key community level initiatives at the biodiversity science-to-policy interface in 2021. IBF also participates in the IPBES Task Force on Scenarios and Models for the 2024-2026 cycle.

BNR developed a new strategic partnership with the International Energy Agency (IEA). The collaboration started with the IEA impactful report Roadmap to Net Zero by 2050 which combined for the first time the IEA's global energy system modelling with the International Institute for Applied Systems Analysis (IIASA)'s Global Biosphere Management Model (GLOBIOM) to provide insights on bioenergy supply, land use and net emissions. The collaboration continues in the context of the World Energy Outlook, where IIASA contributed to the 2022 and 2023 editions, including the regional deep dive in the Latin America Energy Outlook. The work on the 2024 edition is in progress. BNR/AFE contributed to the IEA Bioenergy comprehensive report on "How bioenergy contributes to a sustainable future".

BNR substantially contributed to numerous other assessment reports by international (UN) agencies. For instance, WAT has significantly contributed to various chapters in the United Nations World Water Development Report (WWDR) 2021 on valuing water, which is UN-Water's flagship report on water and sanitation issues, or the State of the World's Land and Water Resources for Food and Agriculture 2021 (SOLAW) report, which is a 10-year flagship report of the Food and Agriculture Organization of the United Nations (FAO) underlining the essential contribution of appropriate policies, institutions and investments. Moreover, BNR provided the land use modeling component of the UNEP International Resource Panel Global Resource Outlook 2024.

Finally, the BNR model GLOBIOM was used to assess the impacts of agricultural trade and support policy reform on climate change adaptation and environmental performance by the OECD. This analysis was made possible in part through the IIASA-OECD strategic partnership. BNR collaborated with OECD also on a technical paper "Policy strategies and challenges for climate change mitigation in the Agriculture, Forestry and Other Land Use (AFOLU) sector".

Private sector

Ultimate validation of the usefulness of the analytical tools, and possibly also the most direct impact on the ground, is delivered next to policy impact through the interest of business actors. BNR was approached by several companies and private sector players over the last years. Thus IIASA researchers collaborated with the FAIRR Initiative – a collaborative investor network that raises awareness of the environmental, social and governance risks and opportunities in the global food sector with over 400 members globally representing over $70 trillion in combined assets – on the development of a new IPCC-aligned climate risk analysis tool for investors, the

Coller FAIRR Climate Risk Tool which provides investors with company-level data on how climate risks may impact costs and profitability in the meat and dairy sector (IIASA PR).

But BNR collaborated also with the Impossible Foods company on a highly impactful study investigating the potential contribution of partial substitution of livestock products by plant-based substitutes to climate mitigation and biodiversity conservation. The resulting article is according to altmetric in the 99th percentile (ranked 194th) of the 357,932 tracked articles of a similar age in all journals and the 99th percentile (ranked 8th) of the 2,221 tracked articles of a similar age in Nature Communications, and the first author was honored as the National Champion for Austria in the prestigious Frontiers Planet Prize.

BNR also supported the BASF company through assessment of biomass availability as substitute for fossil fuels in their material and chemical production processes.

External networks

Besides the network of funders and clients presented above, BNR leads or participates in a multitude of networks of scientists and practitioners, which can be clustered in the following four categories: i) networks of scientists in large scale collaborative research projects, ii) user networks around BNR models and other resources, iii) modelers networks, often engaging in multi-model assessments, iv) other networks of scientists and practitioners.

BNR researchers are currently coordinating four large-scale collaborative research projects from the EU funding program Horizon Europe – ForestNavigator: Navigating European forests and forest bioeconomy sustainably to EU climate neutrality (24 partners from 12 European countries, China and USA), LAMASUS: Land use and management modelling for sustainable governance (17 partners from 8 European countries), NaturaConnect: Building a resilient ecological network of conserved areas across Europe for nature and people (22 from 15 EU countries and UK), and SOS-Water: Water Resources System Safe Operating Space in a Changing Climate and Society (11 partners from 8 European countries and Vietnam). BNR is involved in other 25 Horizon Europe projects as a partner translating into active collaboration with over 100 research institutions.

BNR developed and hosts several flagship models with a large user community which is typically supported by formalized, as well as hands-on, trainings. The hydrological model CWatM is fully open access on Github with a guiding documentation and YouTube tutorials. 15 researchers from China (3), Ethiopia (1), India (2), Pakistan (3), Switzerland (1), UK (2), and USA (3) are actively using CWatM for their projects. WAT has also provided a training to 25 researchers from the International Water Management Institute (IWMI).

Additionally, WAT hosted a three-day training workshop with 31 participants on Water Resources Management in Southeast Asia (review article). This included hands-on learning of CWatM, ECHO and GAEZ. 2 former AFE YSSPs (now Imperial College London (ICL), London/UK, and Royal Technological University (KTH) Stockholm/Sweden) have been trained on BeWhere model with special focus on optimizing aviation e-fuel from Direct Air Capture and electrolysis throughout the entire year in bi-weekly regular meetings.

IBF has also supported with hands-on training and coaching active external GLOBIOM teams BF has also supported with hands-on training and coaching active external GLOBIOM teams around the world. These GLOBIOM teams currently consist of over 60 individual external users, located in 18 different countries, distributed over 6 continents (Asia, North and South America, Europe and Australia). For instance, a hybrid GLOBIOM/GAMS course with 19 participants was organized in 2022. Part of these activities was funded through the EC/GIZ Strategic Partnerships for the Implementation of the Paris Agreement (SPIPA) China project aiming at enhancing modeling capacity building in support to the Paris Agreement implementation, among others

through workshops, such as IIASA-China Expert Dialogue on Long-term and Integrated Modeling Analysis. Examples of work by the external teams include Zhao et al., 2021, Wu et al., 2023, Ren et al., 2023, or in US Wu et al., 2023.

Several BNR Research Groups are contributing significantly to the third phase of the Inter-Sectoral Impact Model Intercomparison Project ISIMIP3, which offers a framework for consistently projecting the impacts of climate change across affected sectors and spatial scales to inform policy decision making on climate change mitigation and adaptation.

WAT has delivered to ISIMIP3 results from CWatM global runs and contributed to five ISIMIP high-impact publications (Satoh et al., 2021, Boulange et al., 2021; Telteu et al., 2021, Reinecke et al., 2021, Pokhrel et al., 2021).

IBF contributed future global land-use pattern for impact simulations, especially for ISIMIP3b, within the PROCLIAS project. And is participating in the Regional Forests and Global Biomes sectorial teams.

AFE contributed within Global Gridded Crop Model Intercomparison (GGCMI) EPIC-IIASA projections to a new, CMIP6-based synthesis of climate impacts on global agriculture published by the Agricultural Model Intercomparison and Improvement Project.

IBF participates also in relevant projects of the Energy Modeling Forum (EMF), such as Assessing Large-scale Global Bioenergy Deployment for Managing Climate Change (EMF-33) and various Integrated Assessment Models outside IIASA use GLOBIOM-G4M for their land-use representation such as the WITCH (CMCC), POLES (JRC), and POTENCIA (JRC) models.

Community leadership

BNR members have been part of leadership and advisory role on various international and European scientific initiatives (e.g., H2020, PRIMA, NEXUS-NESS, H2020 G3P), CMIP6-VIACS (Vulnerability, Impacts, Adaptation and Climate Services, GLASSNET (Global to Local Analysis of Systems Sustainability), International Initiative on Hydrology and Earth System Science for Society, GEWEX, ESA GEO Global Water Sustainability Initiative (GEOGloWS), WWF SBTN (Science Based Targets Network Freshwater and Biodiversity Hub) among others. Y. Wada is also Governors of World Water Council (WWC) which organizes World Water Forum (WWF).

WAT has played an important role in the Groundwater Solutions Initiative for Policy and Practice (GRIPP), which is a global partnership for sustainable groundwater management led by the International Water Management Institute to strengthen, expand, and connect current groundwater research and initiatives.

WAT has been also engaging the Water and Climate Coalition of the World Meteorological Organization, which is a multi-stakeholder initiative to provide tangible action, activities and policy support, for an integrated water and climate agenda with a special focus on data, information, monitoring systems and operational capacity.

WAT is a founding member and co-lead of the Group on River Basin Economic and Policy Modeling (GRBEPM), which aims to significantly improve river basin economic and policy models, and scientific capability, for assessing impacts of water scarcity, droughts, climate change and other driving forces on water-related economic sectors and ecosystems and identifying efficient, sustainable, stable, and implementable water policy interventions. WAT remains an active member of the World Water Quality Alliance led by UNEP and a member of the World Water Council.

AFE continues to be actively involved in the Global Forest Biodiversity Initiative (https://www.gfbinitiative.org/) network, which brings together hundreds of researchers from around the world. In 2022, the GFBI published two papers in leading journals. These articles

analyze global tree biodiversity and its ecological drivers (The number of tree species on Earth & Co-limitation towards lower latitudes shapes global forest diversity gradients).

3.1.3. Program budget and staff

Besides following a set out strategy and fulfilling qualitative targets, the development of a program is also reflected in its quantitative results. In this paragraph, the developments of the budgets, costs, and employees (FTE) of the BNR-program are visualized in 2 tables. This data is reported for the period 2021-2024.

The budget and costs for 2024 are a first, BNR-produced forecast and should therefore only be treated as a first indication, as the fiscal year is still active. This forecast is based on active and signed projects, employed staff with a cutoff date of the end of March 2024, and expected hires for after this cutoff date.

Starting with the budget, Table 3.1 shows a stable consolidation phase after the internal restructuring at IIASA in 2020, followed by a clear growth in 2023. The biggest growth took place within the relatively new BEC-group, from 282K in 2021 to 893K in 2023 (mostly driven by external grants), but all groups showed a stable development in this period. This is also in line with the development of the FTEs (Table 3.2), from which it can be concluded that an increase in scientific employees resulted in an increase in secured external funding.

Based on the first forecast of budget and costs for 2024, this trend of development is expected to continue. For the years beyond 2024 a stable development is expected as well, as the main challenge for all the groups is rather to find the right researchers than to generate additional funding.

Table 3-1 First BNR-produced forecast of 2024 income and costs

	2021	**2022**	**2023**	**2024**
External Projects	€ 3,212,659	€ 3,176,958	€ 3,836,522	€ 5,858,410*
Internal Projects	€ 84,499	€ 155,639	€ 456,266	€ 244,665*
Core budget	€ 1,145,590.00	€ 1,024,359	€ 1,042,158	€ 1,044,642
Total budget	**€ 4,442,748**	**€ 4,356,957**	**€ 5,334,947.**	**€ 7,048,207***
Costs (personnel + non-personnel)	**€ 4,519,332**	**€ 4,353,224.**	**€ 5,320,310**	**€ 7,072,292***
Overhead income	**€ 714,492**	**€ 794,495**	**€ 1,011,285**	**€ 1,234,521***

Overview of staff working in the Research Program (2021-2024)

Elaborating further on the listed FTEs in the previous paragraph, in this section a further analysis of the staff working within BNR over the period 2021-2024 is shown. This overview is based on headcount, and not FTE. Furthermore, some staff members were involved in different roles during this period (e.g. guest and later employee), which means a certain overlap is possible between the types of employment.

Table 3-2 List of staff at BNR 2021-2023

	2021	2022	2023
Scientific FTE within BNR[1]	77.38	84.00	96.93
Non-scientific FTE within BNR[2]	5.40	5.38	6.75
Total FTE within BNR	**82.78**	**89.38**	**103.68**

Geographical diversity

Throughout the period 2021-2024, there were on average 30 - 32 different nationalities represented among BNR employees. Furthermore, guests and associates visiting the institute throughout this period represent a similar number of nationalities (28-33). On top of that, the YSSP's visiting BNR represented 10-13 different nationalities. In total, taking the overlap between these different groups into consideration, 50 different nationalities have worked together within the BNR-Program. Following is an illustration summarizing the countries of origin for the 2023 staff (representing the last available full-year data).

Figure 3-4 Nationalities of BNR staff as of 2023

Employees

From the overall staff, here we further analyse the employees of the BNR-program. In Figure 3-5 the employee distribution over the two main categories is visualized. New (expected) hires for 2024, that are not yet present in the data (starting after 31st or March 2024), have been added to the 2024 bar.

In the following diagram this analysis is projected. New (expected) scientific hires for 2024, that are not yet present in the data (starting after 31st or March 2024), have been added to the 2024 bar.

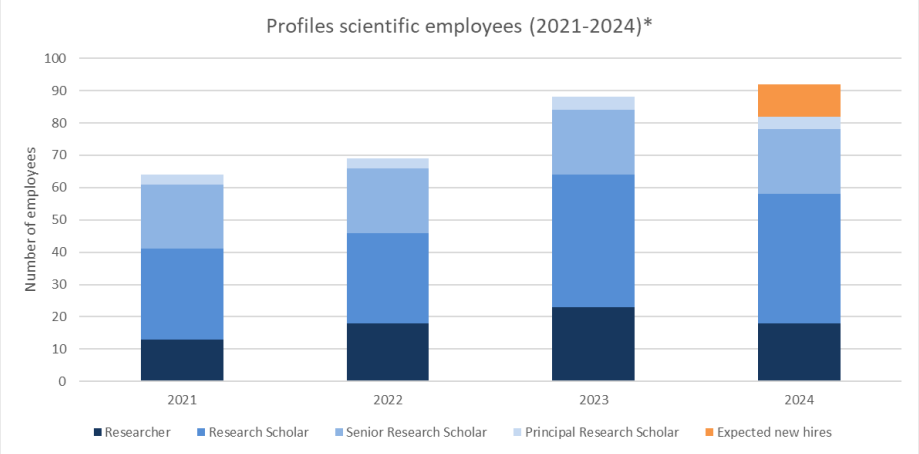


Figure 3-5 List of BNR scientific employees * 2021-2024
*Expected hires added to 2024 column

Externally funded projects (approved from January 2021 to March 2024)

In Annex A of the BNR report, a list can be found of all 161 externally funded projects active between January 2021 and March 2024. Of these projects, 24 are collaborations between two or more of the Groups within the BNR-program. This seems like a relatively small number of cross-group projects, the accumulated budget of these projects however represents 36% of the total BNR externally funded budget (€ 12,5 million vs. € 34,8 million).

With respect to the duration of all externally funded approved projects, only about a quarter of the projects have a duration of 1 year or less, and about 55% are longer than 2 years. Within the shorter projects, several of them are continuously renewed. This structure of the external funding provides solid financial stability and the possibility to strategically plan substantial innovations.

During the period of 2021-2024, the BNR-program cooperated with 71 different funders from all over the world. For some funders there was a single project, while for others the BNR-program was involved in multiple projects.

3.2. Agriculture, Forestry, and Ecosystem Services (AFE)

3.2.1. Summary of achievement of goals and highlights

AFE's research objectives during 2021-2024 focused on both – the further methodological development in order to foster the scientific basis of the group's mostly biophysical modeling, as well as on increasing the group's visibility in terms of participation in or co-organizing of relevant scientific events aiming at policy-relevant national and international processes, and – as a consequence - also on co-authoring of high-level and/or pace setting publications.

Being a critically important component to AFE's goals, the group concentrated on methodological developments aiming at the improvement of our major models including the global crop model EPIC-IIASA, the global forest model G4M, and the natural forest fire and disturbances model FLAM, while also moving further highly innovative approaches including e.g., the linking of forest

and DGVM-type modeling with animal population dynamics and techno-economic optimization modeling (BeWhere). Main emphasis has been put on model integration with the ultimate goal of linking LMS to the BNR initiative iBIOM, model acceleration, and model user friendliness, while the respective progress has been published consecutively.

AFE Land Modeling System – Unique Integration at Landscape Levels

On the model integration side, AFE has been developing an innovative land modeling system (AFE-LMS): an integrated biophysical modelling toolkit designed for advanced assessment of land-based production, ecosystem services, and potentials for nature-based climate and environmental solutions at European and global scales. The AFE-LMS development builds on the existing modelling tools by (a) improving biophysical representation and extending sectoral coverage in the existing AFE's models, (b) deeper integration of the existing models, (c) building common input datasets through harmonization of the most recent and up-to-date European data, and (d) developing data engineering and analytical tools and interfaces enabling linking models and model outputs within AFE-LMS and beyond.

(a) Agricultural model EPIC-IIASA has been extended to consistently simulate ecosystem services across all European cropland and grasslands and reconfigured to incorporate a variety of novel farming options (e.g., crop rotations, crop residue management and other conservation farming practices) and grassland management, which makes it better suited for supporting sustainable agriculture agendas. Agricultural and forest models have been updated to meet harmonized standards for simulating ecosystem C dynamics on mineral and peatland soils.

(b) Sectoral biophysical models have been continuously updated to consistently represent ecosystem services in both time and space, facilitating more straightforward cross-sectoral data fusion and syntheses, starting with C stock and fluxes, commodity productivity, and water balance in Europe. Beyond AFE-LMS, the new-generation model outputs have been included in the integrated biodiversity-land use modelling framework in BIOCLIMA.

(c) AFE-LMS biophysical framework has been updated with the most recent spatio-temporal data on land use and LU management (LAMASUS), European wetlands (ALFAWetlands), and CMIP6 climate change projections (ISIMIP). A novel GIS harmonization interface was developed to increase the interoperability of European, INSPIRE-compliant datasets with the global AFE-LMS modelling framework.

(d) A new AFE team of six experts has been formed to further develop IIASA's Forest Fire and Natural Disturbances Model FLAM focusing on new approaches assess natural disturbances incorporating most recent datasets coupled with technological advancements such as machine learning and neural network (FLAM-Net) approaches. FLAM impact assessments have so far been applied at multiple levels including the Boreal, Tropical, Temperate, Northern Europe and Mediterranean regions, complemented by European and Global future forest fire hotspot identification under climate change and varying forest management scenarios. For precise response modeling of vegetation dynamics to natural disturbances such as fires, droughts, windstorms, and pests/bark beetles, the AFE modeling teams are joining efforts in integrating their models under the AFE-LMS umbrella, using the AFE Integrated Modeling Graphical User Interface (AFE-GUI).

EPIC-IIASA Hypercube – Emulator and Accelerator

On the model acceleration end, multiple AI algorithms, optimization methods and feature engineering pipelines have been developed and tested, providing AFE-LMS with a Data Analyst tier.

EPIC-IIASA Hypercube - consisting of EPIC-IIASA outputs, available in multiple versions each consisting of millions of data records - provides well-structured training data for learning-machine driven statistical model development replicating EPIC-IIASA. Replacing computationally demanding crop modeling with simple statistical models enables for a dynamic interface for data

exchange with integrated land use optimization (or other) models, or EPIC-IIASA emulators could directly serve as dynamic bio-physical modules embedded in more complex modelling tools or services.

Artificial Intelligence and Machine Learning in AFE Biophysical Modeling

The present EPIC-IIASA Hypercube/-Emulator has been further developed beyond training data towards the Crop Model Machine Learning Emulator Suite (CROMES) - created for fast emulation of global crop impacts and adaptation options throughout the CMIP6 climate change projection ensemble. As part of the AFE-LMS development, the agro-environmental modelling team has assumed a new project MACROS (Machine-learning crop meta-models for climate adaptation) that combines the group's process-based crop modelling platform with machine-learning algorithms to harness synergies of both methods aiming at producing crop model emulators that can be plugged into the AFE-LMS and other integrated modelling platforms to derive crop yield estimates on the fly.

AFE Enhanced Research Visibility

In the EU project VERIFY, the AFE team engaged with scientific leaders in the global and European carbon cycle modelling, including its biophysical and human dimensions. AFE contributed the first generation of EPIC-IIASA cropland and grassland carbon flux estimates to a new, consolidated European synthesis of CO2 emissions and removals. AFE is WP leader in the HEU project ALFAwetlands that examines the potential and effectiveness of wetland restoration in supporting transition to a climate-neutral and resilient society and economy, through interdisciplinary advancement of environmental, ecosystem, climate and life sciences, social sciences, and economics and aims to contribute to EU policy implementation supporting climate change adaptation and mitigation, as well as achieving biodiversity targets. AI4SoilHealth (Accelerating collection and use of soil health information using AI technology to support the Soil Deal for Europe and EU Soil Observatory (2023-2026)), is a Horizon Europe Mission SOIL project to co-design, create and maintain an open access Europe-wide digital infrastructure founded on advanced AI methods combined with new soil health measures. Within the project, AFE's agro-environmental modelling team is responsible for a pan-European service on soil health indicators employing and developing models for geospatially explicit and fine-grained predictions. Overall, in the domain of biophysical land use modelling with emphasis on forests, agriculture, grassland and techno-economic optimization, AFE has assumed coordinating or a WP lead in 17+ projects (2021-2024) which tremendously helped to improve its visibility in its particular research field.

AFE Enhanced Research Impact and Policy Relevance

The AFE agro-environmental modelling team has contributed to a range of model ensemble and intercomparison studies and resulting high level publications coordinated by the Agricultural Model Intercomparison and Improvement Project (AgMIP) and the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). These include among others an update of CMIP6-based climate impact projections for the IPCC AR6, cropping system adaptation studies, and wider food system and land use impacts. Most recently, a new project ANFOS has been approved in which AFE will coordinate an AgMIP crop model ensemble study on potential impacts of nuclear conflict on food security. Finally, multiple policy-and community service-related workshops and conferences have been (co-)organized by AFE during 2021-2024, culminating in a in the IIASA-IUFRO-NuBip Forum on Ukraine Science and Education, a high-level event with broad international participation leading to a fundamental needs assessment for the Ukraine forest sector under war, being circulated widely also within International organizations such as the EC, FAO, EFI, IFSA, and the WWF.

Highlights of AFE' scientific output and policy impact

- **A landmark publication in Nature:** Schepaschenko et al. 2021 (Nature) demonstrates novel type of analysis including different sources of information (remote sensing, research forest plots, national forest inventory), as well as the involvement of people with various expertise in the analysis: representatives of academic institutes (Russian and international), education, National Forest Inventory and Forestry Agency. The advanced team and analysis

ensure the breakthrough findings (the role of boreal forest in the climate system is much more important than previously thought) and policy implementation (advanced methodology of forest inventory and GHG inventory).

- **AFE and the sustainability of (well done) Bioenergy**: AFE has been invited by the International Energy Agency (IEA)/IEA Bioenergy to contribute to a comprehensive report on "How bioenergy contributes to a sustainable future" published in 2022 https://www.ieabioenergyreview.org/ available as an innovative publishing concept online and tailored towards a broad readership with special emphasis on policy makers.

- The IEA report has built up on work published in a top-10 GCB cited peer review paper in 2022 with IIASA co-authorship titled "Applying a science-based systems perspective to dispel misconceptions about climate effects of forest bioenergy" has been a profound literature basis for the hot topic of bioenergy and its potential contribution to global climate change mitigation (Cowie et al. 2021, Global Change Biology. Bioenergy).

- **Negative emissions and burden sharing:** Carbon dioxide removal (CDR) figures prominently in modelled pathways to achieve the Paris Agreement's goal of limiting global warming to 1.5-2°C compared to pre-industrial levels.

  AFE research shows that competition among nature climate solutions (NCS) and non-NCS CDR options may arise when ambitious CDR quotas are implemented in countries with vast forest areas or large potential for expansion of tree cover. Therefore, it is important to not use CDR quotas to evaluate national climate actions or to inform climate targets that could exacerbate trade-offs between emissions reduction, biodiversity and ecosystem services in these NCS-rich countries. Instead, results from burden-sharing exercises could foster higher ambition if used to inform voluntary cooperation mechanisms (Yuwono et al. 2023, Nature-Based Solutions).

- **Forest Fires threatening nature, climate, and society:** AFF (Austria Fire Futures) is an example of a proactive, forward-thinking approach to combat climate-change induced challenges, in this case the emergence of forest- and wildfires as a serious threat to human and ecosystem health in Austria. The AFE-led project is a positive step to mitigating future climatic disturbances by promoting the improvement of wildfire prediction, detection, and modeling, as well as consideration of novel factors on natural disturbances, namely the impact of touristic activities on wildfire occurrence and spread.

  However, wildland fires need to be considered a global threat which is why AFE is linking national approaches to e.g., boreal wildfires: The boreal zone has already begun to see harmful impacts to its societies and environment as a result of climate change, from melting permafrost, changes in resource availability, and the increasing occurrence and extent of wildfires. The FLAM team is addressing the strong need for a better understanding of wildfires in boreal forests, including their ignition, spread, suppression, and fire-related emissions, with ongoing research and collaboration. This research is setting the stage to tackle the myriad of challenges facing the boreal zone and boreal forests under climate change (Corning et al. 2024, Fire)

- **Prominent AFE position among frontiers in global crop impact modelling:** - contributes to the last generation EPIC-IIASA projections to a new, CMIP6-based synthesis of climate impacts on global agriculture published by the Agricultural Model Intercomparison and Improvement Project.

  In the VERIFY, AFE has engaged with scientific leaders in the global and European carbon cycle modelling, including its biophysical and human dimensions. AFE contributed the first generation of EPIC-IIASA cropland and grassland carbon flux estimates to a new, consolidated European synthesis of CO2 emissions and removals for the EU.

AFE has contributed with EPIC-IIASA to a series of publications from the Global Gridded Crop Model Intercomparison (GGCMI) initiative, part of the Agricultural Model Intercomparison and Improvement Project (AgMIP) and aligned with the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), covered by various news outlets: Der Standard, Tagesspiegel, Haaretz, Die Welt, FAZ, India Today, ORF, and USA Today: c.f., Jägermeyr et al., 2021, NatFood; Franke et al., 2021, GCB; Zabel et al., 2021, GCB.

3.2.2. SWOT analysis of AFE

Strengths	Weaknesses
• Integration of AFE Models (top priority ongoing process) • Unique expertise strengthening the competitiveness • Specific expertise in biophysical processes • Wide range of models/capacity • Flexibility of models • Attractive/in-demand research topics • We are close to funders, industry, etc... leads to good funding opportunity • Global/multi-level modeling • Computational and infrastructure/platforms • New group formed in 2020 – big strength that we could do a restart • Diversity of academic background of staff members (optimal research/integration/work) • Dynamic group structure • Group structure (sub-groups with team leaders)/dynamic • 1/3 of the group is new – fresh ideas to new concepts etc... • Good coordination within and accross the teams • Cross-program collaboration and external networking • Work as a team and support personal development	• No sustainable income for developing/maintaining long-term models • Lack of institutional support in enabling our work that has the nature of long-term development • Reliance on models (maintenance etc.) makes it difficult for us to address novel and popular research topics (publish high-profile) • Project – reliance is a constraint • We need to use funding from projects in order to live up to our research plan/goals/long-term aims • Competition between groups since each group/program can dive in every topic – no matter if specific expertise or not • Specific expertise (makes it sometimes difficult to find the right experts/expertise) • Limited or no opportunity for capacity development after joining IIASA • Few people per topic - need to further grow • Newcomers need a lot of guidance (to success) - every newcomer needs an experienced supervisor • Difficult integration for newcomers (more systematic and structural approach)
portunities	**hreats**
• Inter- and intra-team/group collaboration- enhance collaboration with other (BNR) Research Groups • Project-dependency is an opportunity to go into new topics • Our topics became popular – so we can try and dominate the discussion based on detailed models/-development/our expertise (ex. NbS) • Collaboration with business • Flexibility of models/technologies covered (e.g. BeWhere) that can make us participating in many different proposals etc... • Computational/infrastructure platforms in development to strengthen our activities • Prominently appear in hI journals but also at conferences with sessions and special issues in journals • Internal capacity building (YSSP, Interns, etc.) • Network enhancement (with chances to co-author nice papers) • Potential new staff through YSSP system • Possibility to grow (get higher level) • RGs group name "AFE" could be changed to "SAFE" - Sustainable Agriculture, Forestry, and Ecosystem Services… to underline the particular focus on integrated sustainability	• Lack of institutional support in enabling our work that has the nature of long-term development --> competitiveness is hindered, management of people is limited, high-level publishing is hindered... • Lacking administration support/lack of computing power • Continuous growth/unsustainable growth (not within our control) • Internal competition • Losing global / multi-level modeling without dedicated institutional support (e.g.,more focus on EU) • Funding needs are threatening internal development • Asymmetric information spread • No space for capacity building • Lose opportunities because of dependence on external funding • Time to write proposals/publications – where to take it from • Intensive work schedule

3.3. Biodiversity, Ecology and Conservation Research (BEC)

3.3.1. Summary of achievement of goals and highlights

BEC had 4 research goals for the period 2021-2024, below we report on progress towards each.

- **Mainstream ecology and conservation into IIASA work** through collaborations with other Research Groups.

In the period 2021-2023 BNR had with 26 projects that included biodiversity research. Thirteen of these projects involved the newly established Biodiversity Ecology and Conservation (BEC) group, thereby contributing to develop and harness IIASA's internal capacity on applied ecological modelling. These projects involved four research Programs (ASA, BNR, POPJUS, SI): bringing ecological knowledge and addressing biodiversity conservation policies in the context of agriculture (Brightspace), forestry (ForestNavigator, BioConsent), climate change policies (BIOCLIMA), economics (ACCREU), equity and justice (FairStream), water management (FairStream, INSPIRE), earth observations and citizen science (Global Foodscapes, OEMC, NatureMap), land system science (LAMASUS, Global Foodscapes), and earth system science (RESIST).

- **Lead world-class research in system analysis applied to ecology and biodiversity conservation problems, through the development of novel theory, data, and models.**

The BEC research strategy 2021-2024 included 5 research foci. We break-down progress towards this goal by addressing each research focus below.

Biodiversity conservation: with the priority topic of **designing terrestrial integrated conservation and restoration plans** that maximize benefits for species, ecosystems and their services, from sub-national to global levels.

Between 1/2021 – 3/2024, the group has published 45 papers on conservation science of which 10 first or senior-authored and 13 publications (5 first-authored) specifically on the topic of conservation and restoration priorities. Of particular relevance for integrated spatial planning are Jung et al. 2021 which is described below. Fastre et al. 2021, instead provides the first global analyses of integrated spatial planning for biodiversity conservation and food production, effectively providing a first assessment of the feasibility and impacts of implementing together the first 3 targets of the Kunming-Montreal Global Biodiversity Framework. The group has harnessed these advancements to develop an approach for integrated spatial planning in Europe (Chapman et al. 2024) that has been developed by the BEC-IBF co-led BIOCLIMA project. BEC also leads the Horizon Europe NaturaConnect project in a consortium of 22 organizations developing a blueprint for the realization of the EU Biodiversity Strategy targets for protected areas.

Macroecology, biogeography, and global change biology: **A priority topic for the next four years will be to study scale-dependent responses** of species' relative abundance, richness, and community intactness to local and regional climate, land cover, and land use. **BEC has published 27 papers on these topics, 7 first-authored**. BEC researchers have also been involved in **several world-leading research projects** for example an analysis of Global Trends of Biodiversity and Ecosystem Services from 1900 to 2050, **recently published in Science**. The group **has also produced an R package** to develop statistical and machine learning models and **repeatable workflows for species distribution models using heterogeneous biodiversity data**. This is currently being applied to identify climate and land-use impacts on biodiversity under alternative policies for agriculture, forestry and nature conservation in the BIOCLIMA, ForestNavigator and Brightspace projects. **Concomitantly, BEC has developed the Hibiiscus model** that allows assessment of the impact of land-use

change on ecological communities, making the PREDICTS framework for the first time replicable through an open-source package. The Hibiiscus modelling framework improves on PREDICTS through: 1) Capacity to model a wider range of biodiversity indicator responses; 2) A Bayesian model formulation that better captures and propagates uncertainty – e.g., spatial effects. 3) Possibility to integrate external biodiversity abundance records – e.g., sPlot and eBird – to improve spatial coverage and improve spatial coverage among different land-use classes in the model training data. **BEC is also leading global research (Science paper and BEC-led research project) on the ecological dynamics and conservation implications of land abandonment**, a conspicuous but insufficiently investigated phenomenon which is now attracting international attention thanks to BEC research.

Bilateral feedbacks between ecosystems and human activities: in particular the modeling of ecosystem services such as pollination and nature-based solutions (NBS). With regards to **ecosystem functioning and associated ecosystem services** BEC has developed and used the PlantFATE model to investigate how phenotypic plasticity, functional diversity and ecological memory can allow forest ecosystems to adapt to elevated CO_2 concentration (Joshi et al. 2023), water availability (Rius et al. 2023), and more generally climate change (Joshi et al. 2022). In the RESIST and fairSTREAM projects, the PlantFATE eco-evolutionary vegetation model has been coupled with the Community Water Model (CWatM, from BNR-WAT). PlantFATE uses climatic variables and water-related outputs from CWatM and in turn returns biophysical parameters, such as soil evaporation and plant transpiration to the CWatM model, which uses them to simulate the water cycle. BEC and WAT are using this coupling to assess the effects of tree species composition on downstream water availability, plant CO_2 uptake, forest biomass, under different climatic and forest management scenarios (i.e. tree diversification, afforestation, deforestation). This framework can be applied for several case study regions and is currently being conducted in the fairSTREAM project, which investigates the food-water-biodiversity nexus across the Bhima basin, as well as, in the RESIST project, which investigates stakeholder perspectives on biodiversity, and ecosystem services provided by Himalayan Forest ecosystems in India. With regards to **pollination,** the BEC group is currently developing a concept for a mechanistic model of archetypical social and solitary pollinators. A prototype, designed to interact with crop models such as EPIC-IIASA, is expected to be ready by the end of 2024.

The nexus between conservation, food production, climate change, and disease risks mitigation
The BEC group has **co-authored 8 publications in the subject, 2 lead or senior-authored** by BEC (Warren-Thomas et al 2022 and Fastre et al 2021). The group also co-leads with IBF the BIOCLIMA project whose aim is to assess the impact of EU land-based climate policies, agricultural policies and biodiversity polices on the achievement of their respective goals, in isolation or combined. The BEC group is also represented in the IPBES Nexus assessment, through Martin Jung who is a young fellow in the assessment and is co-author in several manuscripts in preparations related to this. With regards to health and biodiversity, BEC co-authored a paper on the nexus between food systems, post-pandemic policies and the environment, one on how mammal community compositions predicts likelihood of emerging infectious disease risk and and the recently awarded **Strategic Initiative proposal Eco-Heath**.

- **Marine ecology and conservation**

BEC is partner in the INSPIRE Biodiversa+ project where IIASA is involved in developing analytical framework for planning area-based conservation across terrestrial-marine-freshwater realm. BEC is testing these approaches through leading a research paper "Protecting the edge of the sea" (submission by end of 2024) were we identify and compare top priorities for expanding marine and terrestrial protected areas in Europe, with and without land-sea integration, with the objective of reaching 30% of protected area coverage both on land and on sea. This research addresses the current division of scientific and on-the-ground prioritization work that keeps marine and terrestrial planning separate, neglecting the

fact that many species and ecosystems are sustained by both realms, e.g. seabirds and seals, for example, reproduce on land, but forage at sea.

- **Generate and attract new talent** in macro-ecology, landscape ecology, population ecology, global change biology, biogeography, and conservation science.

The BEC group has grown from 3.5 to 10.5 FTE of research staff employed at IIASA (one Research Scholar shared with EQU) in the period 1/2021 – 5/2024. In the same period program and project officers grew from 0.5 to 2.5 FTE and guest researchers from 0 to 6. The expertise the new team hasbrought in terms of research topics and skills has been in line with the expectations set in the research plan, and functional to its realization through the projects that funded these hires (word cloud from abstract BEC team publications at this link). BEC staff turnover has been low, with only three persons leaving, and all key staff (PIs, task and WP leads) still employed at IIASA-BEC. BEC has the highest representation of ECR and women scientists of all IIASA. Two early career researchers successfully applied to reclassifications to higher functional titles. One member of staff received international awards during their employment in BNR-BEC (SCB Early Career Award) and one has become an independent research fellow and continues.

Highlights of BEC scientific output and policy impact

1. The parties to the Convention on Biological Diversity (CBD) agreed in 2022 on the Kunming-Montreal Global Biodiversity Framework (GBF). The BEC and IBF groups provided substantial input to the GBF negotiations through a range of policy briefs (here and here) and papers directed at CBD parties. The synthesis papers and policy briefs draw extensively on Leclere et al. (2020), Bolam et al (2021), Strassburg et al. (2020), Jung et al. (2021, next highlight), Adams et al. (2021), Fastre' et al. (2021), and Jetz et al. (2021), led or co-authored by IBF and BEC. The GBF background document refers explicitly to these papers in sections related to the theory of change and several goals and targets of the GBF.
2. The BEC group led a key publication in *Nature Ecology and Evolution*, which presented the first global analysis of synergies between conserving areas for species conservation, carbon storage and water provision as well as providing novel insights to guide area-based conservation measures, this work makes several advancements in spatial conservation prioritization methods, e.g. the introduction of methods to reduce biases in spatial priorities resulting from imbalanced coverage of species distribution and the use of innovative mini-max objective functions that ensure that no biodiversity feature (e.g. species) are "left behind", when planning for maximizing species persistence.
3. The NaturaConnect consortium has been asked by the European Commission DG Environment and the Biogeographical Seminar Series consortium to provide scientific support to the European Commission and the Member States by assessing the sufficiency of countries' pledges towards achieving protected area targets and presenting its prioritization approach to guide new protected area designations towards a more coherent and resilient Trans-European Nature Network. The project has also been invited to submit a proposal for indicators of ecological representativeness of protected areas. NaturaConnect proposal underwent review by the EU Biodiversity Platform and is expected to be adopted as an indicator of progress towards qualitative elements of Target 1 and 2 of the EU Biodiversity Strategy. The project is also feeding into regional policy frameworks and processes. Carpathian Convention CoP Decision COP7/9 (October 2023) specifically welcomed the implementation of NaturaConnect and, encouraging Convention Parties to engage with the project.
4. In Summer 2023, the BEC group was commissioned by the European Commission Directorate-General for Climate a fast assessment of the biodiversity impacts of alternative scenarios for the EU 2040 Climate Targets, which was included in the impact assessment accompanying the law. This short study benefited from BNR engagement with the Commission on long-term service contracts, specifically EUCLIMIT

(DG CLIMA, ENER) and BIOCLIMA (DG ENV, CLIMA, AGRI) and marked an important cross-directorate scientific collaboration thanks to IIASA integrated assessment models.

5. The RESIST project hosted within BEC has led a key publication in *Nature Plants*, which highlights how to improve model projections of the global carbon and water cycles under future climate scenarios. By applying a novel modeling framework being based on eco-physiological processes and optimality principles our theory is expected to scale much better to out-of-sample environmental conditions than conventional statistical extrapolations, which therefore allows to capture the synergistic effects of rising CO2 concentrations and rising rainfall variability under projected climate change conditions (Joshi, J., Stocker, B.D., Hofhansl, F. et al. Towards a unified theory of plant photosynthesis and hydraulics. Nat. Plants 8, 1304–1316 (2022).[BD1]

3.3.2. SWOT analysis of BEC

Strengths	Threats	Opportunities
BEC provides methods to investigate ecological systems and conservation needs. Coupling it with IIASA's expertise on social and economic systems allows to investigate ecological externalities of human activities as well as ecological feedbacks that affect wellbeing	Communication can be challenging due to epistemic differences with potential collaborators from other fields	Strong demand for including ecology and conservation in many sectors: e.g. the financial sector's interest in improving quality and transparency of biodiversity impacts disclosures
		Topics related to ecology and conservation research are a requirement on an increasing number of funding calls
BEC staff has a diverse set of expertise, gender, career stage, background that allows the group to take advantage of more and new research opportunities	Turnover: risk of losing essential staff with critical knowledge	Welcoming and collaborative research environment (more likely to retain people)
		Ability to be PI earlier on in the career than in a University setting
		Competitive benefit package, especially for ECRs
Engagement with multilateral environmental agreements, and practical impact in this context: CBD, EU-Green Deal, Carpathian Convention.	Proper engagement at policy level can be time intensive and requires research staff with policy focus	IIASA has an observer status in several international conventions and science-policy platforms
		Most funding agencies provide resources and external support for engagement.
Very strong research network	Staff turnover in partner institutions and at IIASA means that connections can be lost	New staff members from diverse background carry their own research network for the benefit of BEC and the rest of IIASA
		The YSSP program and NMO support provide opportunities to continue and further develop professional relationships
Weaknesses	**Threats**	**Opportunities**
Limited capacity to work on the Global South (GS) due to historical limited funding opportunities and research network associated to GS	Most of the funding streams and research connections are from Europe	SI program, SAC and the Directors can support networking outside Europe and diversify funding
		Researchers from India and South Africa with a network of collaborators in those countries have recently joined BEC
Junior staff has limited experience in turning ideas into competitive grant proposals	Focus on project deliverables and publications limits time and interest in grant writing	Internal and external capacity development and mentoring on fundraising
		The SI program provides an opportunity for grant writing with less competition and administrative burden than most external grants*
Focus on external projects has resulted in fewer interactions among group members than potentially possible	Tight deadlines on project deliverables limits time for brainstorming and collaborating	Creation of thematic groups, e.g. related to methods, can facilitate exchange across people and projects and creative thinking
		**Core budget and some flexibility in delivering on external projects can provide time and resources to develop new ideas
	Collaboration across teams is seen as diluting funding, reducing incentives to collaborate	*This opportunity applies here too
Marine ecology and One-Health are in the research strategy but have no research outputs yet	Lacking institutional precedence, space and time to address this.	Newly hired researchers have marine ecology and conservation expertise and relevant research networks
		**This opportunity applies here too

3.4. Water Security (WAT)

3.4.1. Summary of achievement of goals and highlights

To accomplish its mission, WAT research has focused on three core research areas over the period 2021-2024, described as follows:

Leading global efforts on integrated assessment of water resources availability, quality, and demand

WAT has facilitated several integrated assessments of water resource availability and demand across various spatial scales under future socio-economic and climatic change scenarios using the Community Water Model CWatM, which continues to establish itself as a state-of-the-art hydrological model for modelling from global to local scales, focusing on refining human influence and water management at high spatial resolutions.

CWatM is an active member of ISIMIP project, providing projections of the impacts of climate change on water resources globally. CWatM has been set up at various spatial resolutions in many areas around the world (e.g., Austria, Jordan, India, Israel, Norway, North China, Uganda, the Danube Basin, the Lake Victoria basin). These different versions of CWatM necessitated new developments such as reservoir management schemes, wastewater treatment modules, improvement of calibration and validation processes, post-processing tools and visualizations, and coupling with the MODFLOW groundwater model, OGGM glacier model and GEB agent-based model, which allow us to analyze local water challenges and provide meaningful guidance to improve water management.

Given the critical role water quality plays in assessing water availability, WAT embarked on water quality research by synthesizing the main indicators of eutrophication for global freshwater lake basins and developing water quality modules (e.g., sediment and phosphorus) in CWatM.

Another important achievement at WAT was the launch in 2021 of the version 4 platform of the Global Agro-Ecological Zones model GAEZ, providing interactive data access and visualization. GAEZ v4 represents around 600,000 global layers at grids of 5x5 arcminutes (about 9x9 km) on land and water resources, agro-climatic resources, and crop-specific variables, including agro-climatic potential yield, suitability and attainable yield, actual yields and production, and yield and production gaps. A related development was the update of the Harmonized World Soil Database to version 2.0 (HWSD v2.0), a unique global soil inventory providing information on soils' morphological, chemical, and physical properties at a resolution of about 1x1 km.

Exploring transformation pathways toward a water-secure future

This area of research entails identifying implementable solution options, including technologies, regulatory approaches, and management changes that improve the balance of water supply and demand, ameliorate water quality, and enhance resilience to water-related disasters such as droughts and floods.

Work in this area relies on several modelling tools to support water decision-making and policy at multiple scales. A global version of the ECHO hydro-economic model has been set up and is currently being made open source on GitHub. ECHO has been applied, in combination with different models (e.g., CWatM, GLOBIOM, Input-Output models), to several river basins around the world, including Ebro, Guadalquivir, Lake Victoria, Yangtze, and Zambezi, among others, to assess the cost-effectiveness of adaptation options to water scarcity, water pollution, and droughts and identify optimal combinations of options to address those issues.

WAT has also advanced the macro-economic model DYNAMMICS for assessing disaster risk reduction policies under multiple hazards. WAT has led a consortium to develop the One-Water

Methodology, a methodological framework for systematic yet rapid diagnosis of water security challenges and the development of smart action planning to support governments to move the water security agenda forward. This methodology addresses water security from an integrated perspective, exploring the physical, technological, and governance challenges countries face and opportunities to overcome those challenges. The approach has been tested in 15 countries across Eastern Europe and Central Asia (ECA) and applied to the whole Danube and ECA regions.

WAT also applied state-of-the-art methodologies to assess drought risk in the Western Balkan and Romania, supporting local and regional policymaking and the development of the World Bank Group Country Climate Development Reports.

Assessing social contexts and governance regimes underlying the management of water resources

Given today's accelerated pace of technological development and the comparatively slower pace of social transition, the biggest constraint to future water security will remain what it is today, namely, the human dimension of water management.

To advance this area, WAT researchers have devoted efforts to developing knowledge and innovative approaches to assess the formal and informal aspects underpinning governance of water resources. WAT researchers recommended in an opinion paper a deeper reflection on beliefs and norms — beyond the mere use of science — as an essential catalyst for advancing the frontiers of knowledge co-production. This reflexivity allows debate on the desired goals, means and necessary trade-offs in the climate transition.

WAT's important achievements in co-development range from local-scale communities to national and transboundary watersheds addressing water security themes. Different methods were developed and applied. At sub-national community level, WAT researchers developed the SDG governance toolkit to explore barriers and opportunities to support the implementation of the SDG agenda at the local level and lift institutional capacities about complex sustainability challenges.

Further efforts to develop participatory (bottom-up) governance approaches have been also tested to explore pathways to water-food-biodiversity sustainability in India. WAT has contributed to the design of the participatory strategy to engage with local communities of the Upper Bhima Basin, that also integrates equity and justice principles to promote sustainable resource allocation. The processes and main innovations have been compiled in the IIASA toolkit on co-production methods to assist other researchers within and beyond IIASA in the development of co-production processes.

WAT researchers have also worked closely with local stakeholders in the transboundary Lake Victoria basin to explore and co-develop regional water scenarios, an essential part of sustainability research, as they help make understandable the long-term and upstream-downstream consequences of near-term water management decisions.

Highlights of WAT scientific output and policy impact:

WAT researchers contributed to a new international study that tested the extent to which global water models, including CWatM, agree with each other and with observational data. Using a new evaluation approach, the researchers showed which climate regions the models agree on and where they differ. CWatM has also been used together with several other models, to investigate the timing of unprecedented hydrological drought under climate change globally, demonstrating the benefits of the lower-emission pathway in reducing the likelihood of emergence.

A study published by WAT researchers synthesizes the main indicators of eutrophication for global freshwater lake basins, including the water quality constituents and sources, biogeochemical pathways, and responses of nutrient emissions. The study also developed a new

causal network (i.e., multiple links of indicators) that highlights complex interrelationships among the indicators and provides a holistic perspective of eutrophication dynamics in freshwater lake basins. This study indicates a need for more comprehensive indicators representing the complex mechanisms of eutrophication in lake systems to guide the global expansion of water quality monitoring networks and support integrated assessments to manage eutrophication.

WAT researchers also contributed to a novel international study, showing that river water quality tends to deteriorate during extreme weather events. As these events become more frequent and severe due to climate change, ecosystem health and human access to safe water may be increasingly threatened.

WAT researchers in collaboration with the Lake Victoria Basin Commission (LVBC) worked with local stakeholders from the East African Community to explore and co-develop regional future water scenarios, which are used to identify sustainable water-development pathways to leverage development opportunities and contribute to development and long-term water security.

The complete integration of an implementation agency like LVBC into a research project coordinated by IIASA goes beyond common stakeholder involvement. It enhances the joint understanding of the need for resilient water and food systems and brings research results closer to implementation bodies.

Development of the Global Agro-Ecological Zones (GAEZ) Data Portal. IIASA and FAO cooperated to develop and implement the Agro-Ecological Zones modelling framework and databases for several decades. A Data Portal has been developed for the most recent version, GAEZv4, making results widely and easily accessible to users.

The GAEZv4 spatial data includes numerous assessment results relevant to agricultural production under historical, current and future climates. Results are organized by six major themes: Land and Water Resources, Agro-climatic Resources, Agro-climatic Potential Yield, Suitability and Attainable Yield, Actual Yields and Production, and Yield and Production Gaps.

WAT has contributed to capacity development activities through providing open access to the modeling tools and data, and organizing several modeling workshops and training courses. CWatM is fully open access on Github with an active forum and video tutorials for using it.

WAT also provided a training to 25 researchers from the International Water Management Institute (IWMI) on the use of CWatM through weekly workshops for two months in 2021.

Additionally, WAT hosted a three-day training Workshop with 31 participants on Water Resources Management in Southeast Asia, with hands-on learning of CWatM, ECHO and GAEZ.

Lastly, in the summer of 2024, WAT is hosting a 5-day CWatM summer school to guide beginners through learning and applying CWatM.

3.4.2. SWOT analysis of WAT

• **Strengths**	• **Weaknesses**
• Diverse and complementary expertise and skills (modeling, data analysis, hydrology, economics, governance and policy, stakeholders' engagement) • Well-established inhouse modeling tools (CWatM, GAEZ, ECHO) • Highly motivated, collaborative, diverse and multi-cultural team • High willingness to collaborate internally and externally • A diverse portfolio of ongoing projects (research and innovation, research for development, policy support), some of them extending over the next few years • Agility in addressing short-term assignments • Extended network of international collaborators and involvement in several collaborative platforms (ISIMIP, UN-Water, WWC, WWQA, etc.)	• Limited time for exploratory research and publication and fewer interactions among group members than potentially possible due to high commitment to external projects • Additional skills are needed to be able to address emerging water challenges (gender, NbS, aquatic biodiversity, water supply and sanitation) • Limited scientific IT support • Lack of professional tools (e.g., financial forecasting, project management) to enable better resource and time allocation
• **Opportunities**	• **Threats**
• Advances in AI, EO and big data, enabling better model calibration and validation and application in data-scarce regions • Increasing computing power at IIASA, enabling higher resolution modeling • Growing water management challenges and the need for analytical studies supporting policy formulation and investment decisions • Possibilities to lead projects, especially for Early Career Scientists • Availability of several funding opportunities for Ph.D. and Postdoctoral researchers • Available funding opportunities for water research projects (EU Horizon Program, global donors and foundations) • Potential collaboration opportunities with other Research Groups at BNR and IIASA and other external partners with a strong demand for including water in other sectoral assessments	• Growing external competition in terms of model development and for acquiring funding • Uncertainty in internal and external funding, complicating resource and time allocation and planning • Individualism and knowledge silos • Challenges with staff recruitment and replacement of essential staff with critical knowledge

3.5. Integrated Biosphere Futures (IBF)

3.5.1. Summary of achievement of goals and highlights

BF Research plan was formulated along i) innovations in selected topical areas, ii) foresight and policy support, and iii) strategic objectives. This section follows the same structure.

- **Innovations in selected topical areas**

Four topical areas were identified in the Research Plan: Land, water, and oceans management, Bio-based economic sectors, Shocks, adaptation and resilience, and Food, nutrition, and poverty. And four innovation areas: Spatial scales integration, Temporal scales integration, Heterogeneity of economic actors, and Value chains.

In the area of **Land, water, and oceans management**, substantial innovations were achieved along several dimensions.

First, a comprehensive representation of relevant nitrogen flows was implemented in the Global Biosphere Management Model (GLOBIOM) and applied to a study published in Nature Food, which demonstrated that with existing nitrogen surplus mitigation options and international trade, we can reconcile regional nitrogen boundaries with global food security. The model has been also enhanced by new, policy relevant, forest management options – close-to-nature management and set-asides – and used to analyze the impact of European forest management strategies on the global species extinction risk.

The study found that ambitious biodiversity protection action in European forests would, through international trade, lead to the increase of global extinction risk. In order to further enhance our capacity to analyze forest management impacts on biodiversity through better representation of deadwood, a novel model was developed, allowing to project the current deadwood distribution as a function of environmental and socio-economic factors, and its future development in response to management and climate change.

The first step towards integrating the blue economy into our modeling system was made in collaboration with a YSSP student from University of Queensland, who developed a spatially explicit database of the technical and economic potential of marine farming of 34 commercially important seaweed species and in an impactful Nature Sustainability paper, article is in the 99th percentile (ranked 1,990th) of the 478,216 tracked articles of a similar age in all journals and the 93rd percentile (ranked 4th) of the 60 tracked articles of a similar age in Nature Sustainability, studied land related environmental benefits of seaweed substitution in food, feed, and fuel supply chains (cf. Section 5.2, where also achievements in land-based climate mitigation research are summarized).

Under this topic, IBF also started a new era of producers representation in terms of **heterogeneity of economic actors**, when it developed capacity to use the farm accountancy data network (FADN) dataset, which monitors income and business activities of over 80,000 farms across European Union, and thus allows development of production system typology with highly disaggregated cost items, which will in a new AgEnRes project allow also for better integration of the agricultural and energy sectors. Several new developments under this topic are underway in the newly contracted projects, such as ForestNavigator and LAMASUS, both coordinated by IBF, but also ACT4CAP27, ALFAwetlands, AMIGDALA, or BrightSpace.

Forest industry capacity to substitute coniferous, non-coniferous and recycled biomass on the competitiveness of traditional forest industry regions was analyzed under the **Bio-based economic sectors** topic. The economic availability of biomass is a burning question for the industry, as also shows the IBF analysis for BASF, who contracted IIASA to estimate the economic potential of biomass for chemical industry. This study also benefited from an IBF-led international research on benchmarking costs of harvesting from industrial plantations in different global regions.

Under this topic, also the research on international trade was advanced, particularly through the development of a highly disaggregated trade cost representation for Africa to analyze the potential impacts of the African Continental Free Trade Area (AfCFTA) on agricultural markets, food security, and environment, published in Nature Food.

As a recognition of the novelty and policy relevance of our work, a former article on international trade and adaptation was invited by Nature Climate Change to be converted into a Policy Brief in their new series. GLOBIOM was used to assess the impacts of agricultural trade and support policy reform on climate change adaptation and environmental performance by the OECD.

The work on sustainable supply chains for biofuels was pursued in a study on uncertainty in lifecycle greenhouse gas emissions of sustainable aviation fuels, as well as in a Nature Sustainability study on virtual trade flows related to China's growing food demand.

Finally, new projects have been started – CLEVER and RAINFOREST – to further develop the aspects of **value chains**, including actor heterogeneity.

For **Shocks, adaptation, and resilience**, IBF led the contribution to the joint IIASA-ISC (International Science Council) initiative Bouncing Forward Sustainably: Pathways to a post-COVID World on the resilience of food systems. Climate impacts were assessed at global scale under the AgCLIM50-IV project which looked at the potential for irrigated systems to be used as an adaptation strategy for climate change and as part of the ISIMIP3b project. Impacts of climate extremes were assessed as climate storylines under the RECEIPT project, leading to a paper on the impacts of an increase in simultaneous soybean failures. Climate change adaptation pathways for the agricultural sector were also studied for Gambia.

The **temporal scales integration** was then explored in a Nature Food paper focusing on thee rice sector in Africa, which possibly for the first time in a consistent framework analyzed both the impacts of long-term gradual climate change and impact of climate variability on agricultural markets.

Finally, IBF work on the impact of climate extremes and natural disturbances on the forest carbon sink was published in the European Commission Impact Assessment of the 2040 Climate target.

The work on the topic **Food, nutrition, and poverty** was pursued along two intertwined tracks – future diets and consumer heterogeneity. In collaboration with Impossible Foods a highly impactful study about the benefits of partial substitution of livestock product by plant-based equivalents on climate and biodiversity was published in Nature Communications. While the benefits of sustainable healthy diets were extensively discussed in the literature, we also looked at what would be the level of tax necessary to incentivize the shift to healthy diets.

Finally, in a recently published Nature Sustainability study, we demonstrate that dietary change due to urbanization will have in Africa a far larger impact on land use change than the mere expansion of the settlements. Following the Research Plan, and to bring the **heterogeneity of economic actors** also on the consumption side, we have started projects, CHOICE and SWITCH, where we disaggregate food demand by age and education, to be able to better link with the IIASA disaggregated population projections, and to better assess the health impacts.

- **Foresight and policy support**

As extensively presented in Section above, IBF further strengthened its position as a **trusted partner in concrete policy and regulatory processes across all continents;** in Europe (European Commission), in North America (US Environmental Protection Agency), Latin America

(Governments of Argentina and Colombia), Asia (China, India and Indonesia), Africa (Gambia and Uganda), in Australia, and at the global scale (UN International Civil Aviation Organization). It also reached a new milestone in the foresight area, when it became a strategic partner for the International Energy Agency to collaborate on the authoritative World Energy Outlook by providing the land use component.

Forward-looking scenarios based on the Shared Socio-economic Pathways represented the backbone of a multitude of impactful papers, including more recently Daigneault et al. (2022) or Pereira et al. (2024). IBF is currently working on the new generation of these scenarios.

- **Strategic objectives**

Integrated BIOsphere Management modeling framework (iBIOM) is a truly BNR-wide activity, although led by IBF, and therefore it is extensively elaborated in Section 1.1. Here, we thus focus only on two key elements developed in IBF. First, **spatial scales integration** is one of the challenges when linking BNR models within iBIOM; while the economic model GLOBIOM provides generally country level results, biodiversity or hydrological models, and even the dynamic forest management model (G4Mm) operate at a high spatial resolution, thus downscaling is necessary. The downscaling is done using Bayesian statistical models (Krisztin et al. 2021 and Krisztin and Piribauer 2022). downscalr is an R package which was developed by IBF for downscaling of land-use and management projections, within an EC/GIZ funded Strategic Partnerships for the Implementation of the Paris Agreement (SPIPA) Argentina project aiming at enhancing Argentina's modeling capacity in support to the Paris Agreement implementation. The package was further developed in the context of the European Union Biodiversity and Climate strategies Assessment (EU BIOCLIMA) project. It is fully open source, and has been adapted also for non-BNR models, incl. CAPRI and the FABLE Calculator. Another important step towards the full iBIOM, is the implementation of a fully automatized execution of its "kernel" through a scripted workflow connecting GLOBIOM, G4M, downscalr and several biodiversity models.

Vibrant consortium of GLOBIOM users and developers is under continuous development. Currently, 86 external users from 18 countries have access to the model code and data through a github repository. 19 researchers participated in a dedicated 1-week GLOBIOM course offered by IBF in 2022. In addition, 25 YSSP students, 1 IIASA-NERC and 4 PKU-IIASA postdocs, 1 CSC scholarship, and several external collaborators, including PhD students and post-Docs from Australia, Canada, China, India, and the U.S., benefited from hands-on training during their IIASA stays or online support. Training activities were also supported by the European Commission GIZ (SPIPA) for India and China. The users are supported also by a recently developed model documentation and a GLOBIOM wiki. External partners led 10 publications since 2021, published among others in Nature Climate Change (1), Nature Food (3), Nature Sustainability (3).

In the framework of the ForestNavigator project, IBF is **convening an international stakeholder community** as the Forest Policy Modeling Forum. The Forum is a platform where policy makers dealing with various facets of forests and of the forest sector meet with modelers in an informal dialogue to better understand each other and to make the modeling work even more relevant for the policy support. Initially, participants from Europe, China, and United States are invited for the first meeting in September 2024. The possibility to expand this Forum to a global platform will be explored.

Highlights of IBF' scientific output and policy impact

- **The new hotspot – Africa: Research and policy impact:** The African continent is the hotspot of sustainability challenges, but analytical tools to accompany the necessary transition to sustainability are badly missing. IBF, in collaboration with PhD students from KU Leuven, developed a regional version of GLOBIOM, with a specific focus on the African

continent to address trade-offs between the three dimensions of sustainability and to find solutions in this realm.
First, the researchers analyzed how continental free trade and agricultural development could ensure sustainable food security for Africa, leading to a publication in Nature Food. Another study published in the same journal investigated climate change impacts, including climate variability, in the context of alternative socio-economic scenarios.

Finally, the impacts of urbanization and related preference shifts on land use were investigated and published in Nature Sustainability. At a national level, policy engagement took place in the context of an FAO funded project in Uganda, where IBF participated in a modeling consortium to support governance innovation for food system transformation. In The Gambia, IIASA and project partners developed scenarios with stakeholders including the Ministry of Agriculture, Health and Climate Change and The Gambia Bureau of Statistics.

- **Fundamental contribution to land-based climate mitigation science:** IBF has continued its leadership in the land-based mitigation modeling community, which has led to multiple high-level papers contributing to improved understanding on what land use can contribute to the Paris Agreement target. Studies assessed synergies and trade-offs of ambitious land-based mitigation pathways with other Sustainable Development Goals such as food security or biodiversity, and tried to identify integrated no-regret solutions across targets.

  While climate change is a truly global problem, the implementation of mitigation policies is national, and often even subnational. Here, IBF contributed by assessing Nationally Determined Contributions and identifying the emission gap. IBF also quantified the effectiveness of a unilateral EU climate change mitigation policy in the agricultural sector ("Research Highlights" of Nature Food) and together with JRC investigated policy implications of the short-lived character of methane (Nature Food). Moreover, IBF together with PKU quantified implications of the Chinese climate neutrality target (Nature Food) and its sustainability implications in- and outside China, and assessed the contribution of nature-based solutions for Brazil's net zero target.

- **Continued support to regulatory processes:** IBF is providing continued support for the estimation of market-mediated impacts and induced land-use change effects of both road and aviation biofuels around the world. For example, GLOBIOM is one of the two models considered by the Carbon Offsetting and the Reduction Scheme for International Aviation (CORSIA) to quantify ILUC factors for alternative aviation biofuels within the International Civil Aviation Organization (ICAO) Fuels Task Group. IBF has continued to support CORSIA process with its GLOBIOM model also in the most current cycle of Committee on Aviation Environmental Protection (CAEP).

  IBF is an integral part of the biofuel modelling community for policy support and is regularly invited to policy workshops (US EPA biofuel and GHG modelling, 3rd Energy Transition Working Group of the G20). Moreover, IBF has also a longstanding partnership with policy makers such as the US Environmental Protection Agency (EPA). Based on GLOBIOM simulations, EPA announced the Final Renewable Fuels Standards Rule for 2023, 2024, and 2025 on June 21, 2023 (IIASA news). The rule establishes biofuel volume requirements and associated percentage standards in view of steady growth of biofuel use in the US's fuel supply and aims to ensure a sustainable and environmentally friendly energy future.

- **Productive partnerships with the private sector:** IBF researchers (co-)authored more than 130 scientific articles, 28 of them published in the Science/Nature family of journals.

  A highly impactful publication in Nature Communications, article is in the 99th percentile (ranked 195th) of the 358,816 tracked articles of a similar age in all journals and the 99th percentile (ranked 8th) of the 2,220 tracked articles of a similar age in Nature Communications, found that replacing 50% of meat and milk products with plant-based

alternatives by 2050 can reduce agriculture and land use related greenhouse gas (GHG) emissions by 31% and halt the degradation of forest and natural land. Additional climate and biodiversity benefits would accrue from reforesting the spared land. The restored area could contribute up to 25% of the estimated global land restoration needs under Target 2 of the Kunming Montreal Global Biodiversity Framework by 2030. This is an example of successful collaboration with the private sector, in this case Impossible Foods.

Another example would be the contribution to the Coller FAIRR Climate Risk Tool which provides investors with company-level data on how climate risks may impact costs and profitability in the meat and dairy sector (IIASA PR).

- **Fund raising and community leadership:** IBF has been leading the IIASA contribution to 74 externally funded projects with a total IIASA budget of about 16 million euros. IBF was also extremely successful in bringing together large research consortia and developing with them project proposals.

  Currently, IBF coordinates two Horizon Europe projects. The ForestNavigator project (EUR 6.5 million) was launched in 2022 and brings together 24 research institutions from 13 EU countries and China to support the European Commission and national authorities in designing robust sectoral policies addressing forests and the forest sector for achieving climate neutrality in the EU. The LAMASUS project (EUR 5.6 million), also started in 2022, and, with 16 partners, aims at providing a novel governance model, and the tools required to build sound policies for the transition required by the European Green Deal.

3.5.2. SWOT analysis of IBF

Strengths	Weaknesses
• IBF modeling framework (GLOBIOM/G4Mm) and team is trusted by clients and partners • The modeling framework is unique in the detailed coverage of both agricultural and forest product (international) markets in a spatially explicit bottom-up setup • The modeling framework is unique in its reputation for both global, often academic, as well as national, often in direct support to policy makers, applications • The modeling framework is linked/integrated not only to BNR models, but also to other IIASA flagship models, as well as leading non-IIASA models • Diversity, expertise and external recognition of IBF staff, incl. track record in high impact journals • Strong network of collaborators and clients • Capacity to attract external funding	• Full integration in the modeling framework of aquaculture, seafood, and blue economy in general is still work in progress • Too much focus on the environmental dimension of sustainability as compared to economics and social aspects although the modeling framework is based on solid economics, and steps towards covering the social dimension are underway • Large reliance on external funding leads to underinvestment in model consolidation and documentation, user community support, publications, and communication in general • Lack of standardization and complexity of the research approaches lead to too high cost, and thus lack of competitiveness for specific opportunities
Opportunities	**Threats**
• Increasing awareness among decision makers about the inseparability of individual development goals, and thus the recognition of the need for formalized integrated approaches • Biomass is gaining on importance as a potential substitute for fossil-based energy and materials, leading to increased interest by decision makers, including industry, into economic availability assessments • Increased interest in Europe in business competitiveness and social impacts of policy decisions will direct funding into novel research areas within IBF reach • Development funding often interested in national level assessment, where competition is smaller than at the global scale or in Europe • New IT technologies to become a modeling community hub • Turbulent geopolitics intensify interest in international trade analysis	• Reduced interest by policy makers in science-based decision support, and in research in general • Funding opportunities tempting to disproportionately focus on Europe at expense on other regions/countries • Not keeping pace with new technologies • Difficulty to attract and maintain key team members because of shrinking pool of qualified candidates on the one hand, and increasing competition for them, on the other hand

The complete report of the Biodiversity and Natural Resources (BNR) Program is available at the following link: BNR Self-assessment report 2021-2024.

4. Program: Energy, Climate, and Environment (ECE)

4.1. Overall Program Achievements 2021-2024

4.1.1. Research Goals and Achievements

The objective of the ECE Program is to understand the nature, dynamics and pace of feasible systems transformations that can address environmental problems in a socially and economically sustainable manner. Addressing climate change while assuring human health and wellbeing, and the reduction of social inequalities, implies rapid and unprecedented structural changes to reach, e.g., net-zero GHG emissions over the next decades. Our focus is on exploring regional, national and local policy decisions and actions required in the short term to put the world on track for achieving long-term targets. We study how to accelerate technology diffusion and substitution dynamics, while also exploring the governance needs and social innovations that are required for this. The Program's niche builds upon the systematic and holistic analysis of energy policy objectives and their interactions to identify possible synergies and trade-offs. This includes the identification of salient co-benefits from meeting a range of environmental, economic, and social objectives that at the same time are robust against multiple uncertainties that the future entails.

ECE comprises four closely integrated **Research Groups**. Research on global, regional and national transformation pathways in the Integrated Assessment and Climate Change Research Group (IACC) is complemented by bottom-up and more local studies in the Pollution Management Group (PM). The Sustainable Service Systems Group (S^3) focuses on demand-side transitions and disruptive end-use innovation, lifestyles & behavior – thus going beyond the traditional supply-side bias of climate mitigation studies. Finally, the Transformative Institutional and Social Solutions (TISS) Group is critical since it permits the integration of social science perspectives into quantitative transformation pathways, with specific focus on governance and institutional change as well as poverty eradication, equity, and justice. A fifth Group on Integrated Climate Impacts has just been established to further help integrate climate mitigation, adaptation, and impacts across ECE (and the rest of IIASA). Most ECE staff have affiliations across multiple ECE Research Groups (and Programs) to assure integration of research across the domains. In addition, ECE has established **six Cross-cutting Research Themes** each led by Senior Researchers that further facilitate integration and collaboration across the Groups, helping co-create the research agenda. Multiple internally and externally funded research activities coordinated by ECE also involve other IIASA Programs and help leverage synergies particularly in the areas of just transition and decent living (POPJUS/EF/SI), climate modelling (ASA), integrated assessment (BNR), biodiversity assessments (BNR); energy, water, land nexus (BNR), impacts and adaptation (ASA/BNR/POPJUS), SSPs (BNR/POPJUS/ASA), and carbon dioxide removal (ASA).

From a **methodological perspective,** ECE work aims to both enhance and extend the presently available tools (e.g., the MESSAGEix IAM framework and GAINS) and to develop novel operational methodologies. In the period 2021-2024, a framework of tools has been developed, which is interlinked and can be flexibly adapted to address various research objectives and their integration, rather than focusing on many independent and dispersed tools for which a critical mass of research capacity is difficult to maintain. Extensions of the modeling framework have focused specifically on 1) novel tools to better understand lifestyle and behavioral changes and the barriers of the sharing economy (LIFE in collaboration with Oxford University), demand-side tools of the build environment (CHILLED and STURM); 2) granular agent based models to understand city transitions (BENCH), 3) new material supply and demand modules, including circularity, which is critical for understanding industrial transformation away from the currently energy intensive economy to a more material intensive one, 4) integration of biophysical climate impacts into the IAM framework through novel emulator approaches (RIME, CHILLED), and 5) continued systems integration of air pollution, short-term forcers and climate change through coupled modeling (GAINS-MESSAGEix).

Research on **climate transformation pathways** has played an important role in the period 2021-24 due to the coalescence of major international assessments and ECE's leadership in IAM model comparisons feeding into those assessments. An overarching strategic objective of the research was to support international policy through the identification of critical regional and global systems milestones for limiting global warming to 1.5C as stated by the Paris Agreement. Specific focus has been on exploring the remaining carbon budget (Riahi et al., 2021; Rogelj et al., 2023; Gidden et al., 2023) as well as how to manage the increasing risk of overshooting the agreed targets (Drouet et al., 2021, Rogelj et al., 2023). Our work has further contributed to a better understanding of net-zero emissions systems (Riahi et al., 2021), the required investments and finance (Bertram et al., 2021), as well as sectoral transition needs (Hasegawa et al., 2021; Guo et al., 2022). The Program assumed a leadership role in the community by coordinating the major modeling comparisons feeding into the IPCC (more than half of all Paris-compatible mitigation scenarios assessed in the IPCC Sixth Assessment Report (AR6) were developed in projects led by ECE-IIASA, Riahi et al., 2021); co-leading the key chapter on "Transformation Pathways" (WGIII: Riahi et al., 2022) and contributing as Lead Authors to several other chapters in the AR6.

Gaining a better understanding of the **demand-side of the system is critically important** since demand "sizes" the overall challenge, and since changes in demand can occur more rapidly through the reliance on granular and distributed technologies - as compared to the supply-side, which is characterized by relatively slow technology diffusion and policy inertia (Wilson et al., 2020). Building upon pioneering work in the past on low energy demand scenarios (LED: Grubler et al., 2018), ECE focused in 2021-2024 on a blend of activities to design the so-called "High with Low (HwL)" pathway (Wilson et al., 2023). HwL aims at a set of measures and policy packages (combining sharing economy elements with circularity) that can achieve high well-being with low resource inputs. Several recent studies have focused on the role of behavioral change, e.g., assessing the role of peer influence in adoption of clean technology (Niamir et al., 2024), as well as exploring benefits of behavioral options in a post-COVID environment (Kikstra et al., 2021). An important insight of the studies is stressing the large cost-effective near-term mitigation potential of demand-side "Avoid-Shift-Improve" measures, e.g. with a potential of reducing >60% of emissions in the buildings sector (Mastrucci et al., in review). A major achievement in this area is the establishment of a global research community (EDITS) focusing on demand-side solutions to mitigation. EDITS is co-convened by IIASA and Japan-RITE. It has led to dozens of community research activities enhancing our understanding of demand-side changes and pushing the frontiers of modeling for quantitative low demand scenario applications in different sectors (e.g., Mastrucci et al., 2023, Wiedenhofer et al., in review, Thomas et al., in review).

Mitigation of non-CO_2 GHG is an essential and ever more urgent element of strategies to address climate change and to limit the overshoot of stringent global warming goals. ECE contributed to the UNEP methane assessments (UNEP, 2021; 2022), and focused on several key, often poorly understood, aspects of non-CO_2 sources and their mitigation, including novel options to mitigate farmland N_2O emissions through bacterial sources (Hiis et al., 2024). A first global SSP assessment of GHG emissions and mitigation potential from circular waste management systems was conducted (Gomez-Sanabria et al., 2022), and then further developed considering also the leakage to aquatic environments (Gomez-Sanabria and Lindl, 2024). From a policy perspective, we showed the need to go beyond the Kigali Amendment to the Montreal Protocol in order to make F-gases and HFC emissions compatible with the Paris Agreement goals (Purohit et al., 2022), contributed to the **International Nitrogen Assessment** - a major compendium of the global advancements of nitrogen research scheduled for publication in 2025, also providing insights about the role of nitrogen in climate and pollution, of which one highly policy-relevant aspect is how actions addressing nitrogen pollution can reduce premature mortality (Gu et al., 2021).
Policy analysis on the **health and ecosystem benefits** of mitigation and pollution strategies across varied spatial and temporal scales were conducted in support the European Commission, UNECE Air Convention, UNEP, Climate and Clean Air Coalition, and the World Bank. Several Lancet studies were conducted in collaboration with the health community (Watts et al., 2021;

Romanello et al., 2021, 2023; Hamilton et al., 2021; Zhang et al., 2023; van Daalen et al., 2024), including the most recent Lancet Countdown, which builds upon a new ECE indicator, that permits splitting mortality from ambient air pollution by economic sector. Novel decomposition approaches permitted a further study of the impacts of population dynamics for the resulting health co-benefits (Rafaj et al., 2021). Exploring the severe **pollution inequalities** in India, we show that while the burden is generated by the wealthy, the poor suffer most of the associated health impacts (Rao et al., 2021). In a new area of research, ECE scenarios for **mercury** (Hg) assessed the complementary role of targeted Hg control policies in addition to stringent climate and air pollution controls (Brocza et al., 2024). Finally, considering the important role of aerosols in climate forcing, ECE supported the Arctic Monitoring and Assessment Program (AMAP, 2021), highlighting the important role of air quality policies in order to **slow down Arctic warming** (von Salzen et al., 2022).

Several ECE research activities in 2021-2024 aimed to **increase policy realism** through a better integration of social sciences into systems-engineering and economic modelling. This comprised specifically pioneering work on 1) the role of **governance** and institutional changes (Andrijevic et al., 2020; Gidden et al., 2023), as well as 2) a systematic exploration of the different dimensions of **feasibility** (Brutschin et al., 2021). In the latter area, ECE established a novel conceptual framework that underpins the IPCC assessment of feasibility of mitigation pathways, and which illustrates that the main feasibility concerns are not technological or economic, but rather connected to the lack of effective governance and institutions in many developing countries. In the latter area, empirical assessments of the determinants of governance were conducted as a basis for future projections of governance and institutional change (Andrijevic et al., 2020). This, together with empirical work on the relationship between environmental effectiveness and governance capacity, has laid the foundation for a first modelling study with endogenous representation of governance as a mitigation barrier in the global south (Gidden et al., 2023). Impact of the research was amplified through the uptake of the methodology by the IAM community in its recent modelling intercomparison project on the role of governance/institutional capacity in mitigation (Bertram et al., accepted in NCC – policy brief). Insights that have emerged from this study, suggest that the challenges to reach some climate goals might be larger than anticipated earlier (e.g., by the IPCC), but also that there are important enabling conditions that can help to address the governance challenges.

In 2021-24 ECE made significant methodological and conceptual strides in incorporating **poverty eradication, equity, fairness and justice** concerns into transformation pathway analysis. At the heart of this is a comprehensive bottom-up framework for defining "Decent Living Standards" (DLS: Rao et al., 2018), which forms the backbone of new advanced modeling tools from industrial ecology, including input-output and lifecycle analyses. These methodological advances have provided the foundation for exploring the poverty dimension of sustainable energy demand pathways. In a first-of-its kind analysis we have quantified decent living gaps and energy needs around the world (Kikstra et al., 2021), illustrating the critical role of embodied energy and material requirements of infrastructure in the developing world. ECE has also developed, together with colleagues from the POPJUS Program, a new conceptual framework for how to systematically include justice and fairness considerations in climate mitigation and scenario analysis (Zimm et al., 2024). The framework underpins the current community effort led by IIASA-ECE to conduct a justice model intercomparison (JustMIP) employing integrated assessment models (IAMs). The work is supported by both the Earth Commission and was endorsed recently also by the UN group of high-level representative advisors at the 2024 UN Science, Technology and Innovation Forum. For the communication of the research ECE developed a series of innovative web-based tools, including the Fair Mitigation Finance Explorer, which allows users to explore 'fair' regional contributions to mitigation investments (Pachauri et al., 2022), as well as the Carbon Debt Tool offering stakeholders insights into carbon debt and credit projections, fostering the understanding of regional 'fair' shares in managing the transition to net-zero and related responsibilities for overshooting climate targets (Pelz et al., submitted).

Research on **technology innovation** has aimed to provide a better understanding of the patterns, drivers, constraints, and impacts of technological change, particularly in areas that are key for framing global sustainability conditions. Specific focus has been on exploring the role of **granular technologies** and their potential in acerating technology transition through more rapid diffusion and innovation potential (Wilson et al., 2020; Wilson et al., 2023), as well as the role of **digitalization** as a major driver of innovation with a high potential for decarbonization, but also as a source of additional resource use with the potential to negatively impact planetary stability (Wilson et al., 2020 and Creutzig et al., 2022). Empirical analysis on the diffusion dynamics of granular technologies and their potential for economics of scales were translated into a novel modelling formulation of technological learning (Pratama et al., forthcoming).

The work on technology patterns was complemented by research on promising new individual technologies or technology clusters. The technologies are selected from areas where critical innovation gaps exist in order to reach, e.g., a net-zero emissions system. Two main technology clusters studied in 2021-24 include 1) **carbon dioxide removal** technologies (CDR) and 2) unconventional **energy storage technologies**. Research on CDR is supported by a "synergy grant" of the European Research Council (ERC), and combines empirical work, surveys, structured reviews and modelling. We explore new technological options (such as Direct Air Capture and Storage) as well as the portfolio of nature-based solutions (ranging from afforestation and biochar to sustainable bioenergy supply with CCS). In the area of energy storage, ECE is pioneering new storage technology designs, ranging from gravity-based storage systems (e.g., in lifts, mines, trucks), to buoyancy and deep ocean hydrogen and compressed air storage technologies. Global potentials and costs of these technologies have been assessed in a series of papers (Hunt et al., 2021a, 2021b, 2022a, 2022b, 2023a, 2023b, 2023c, 2023d, 2024) The work received widespread attention by the media as well as the industrial sector with multiple start-ups (Green Gravity, Economical Energy), commercial implementation on the ground (China lift energy storage buildings), and government programs (e.g., deep coal mine storage initiative in Romania).

ECE has established itself as a **community data hub**. Following IIASA's role as the host of the RCP and SSP data sets for the scientific community, ECE has invested in the development of a more versatile and user-friendly Scenario Explorer infrastructure that is currently being used in more than 40 international multi-model applications. Building upon ECE's role as a hub for scenario data within the broader scientific community, a formal "Agreement of Collaboration" was established between IIASA, IPCC, and the IAMC, giving responsibility to IIASA to host the IPCC AR6 scenario data sets (Byers et al., 2022). The ECE scenario databases serve multiple purposes, helping with quality control and comparability of data sets from different modeling groups, as well as for data dissemination, transparency and communication. The databases have developed into a central service for scenario users and the integrated assessment modeling community itself, with demand being substantial: over the course of 2023, the scenario datasets were downloaded more than 15,000 times by 90.000 users.

From 2021 to 2024, the ECE's in-house research effort averaged 65.5 scientific person-months per year, supported by an annual budget of €4,850 million, approximately 71.4% of which was externally funded. During this period, ECE researchers produced a significant body of work, including 569 peer-reviewed journal articles, 46 book chapters/books, 24 research/policy reports, and 56 other publications. Notably, 98 of these publications appeared in prestigious journals such as Science, Nature, and the Nature cluster of journals accounting for more than 60% of all IIASA publications in these top-tier journals during this timeframe.

In 2023, six ECE staff members were recognized as highly cited researchers globally and were included in Reuters' list of the top 1000 most influential climate scientists. Among them, ECE Program Director Keywan Riahi was ranked first on this prestigious list.

4.1.2. Policy Impact

The ECE Program has been highly successful in engaging a range of key stakeholders from government, civil society, and the energy industry through one-on-one consultations with key decision makers and presentations at international conferences. In this section, some selected Program contributions to international policy reports and activities are summarized; it aims primarily at highlighting some of the main activities while not attempting to be fully comprehensive.

At the international level, ECE provided critical inputs to several high-level initiatives, including the United Nations High-level Political Forum (HLPF 2021 and 2022), where ECE organized and participated in multiple inter-ministerial sessions on the implementation of the 2030 Agenda. The Program Director of ECE, Keywan Riahi, has been appointed to the **UN Secretary-General's Group of Ten High-level Representatives** for two successive terms (2022-2023 as well as 2024-2025). The UN "10-Member-Group" of High-level Representatives of Civil Society, the Private Sector, and Scientific Community support the UN Technology Facilitation Mechanism and the UN interagency task team on science technology and innovation (STI). ECE scientist, Shonali Pachauri, also serves on the **SDG7 Technical Advisory Group**, feeding the Programs work directly into efforts to achieve the energy related sustainability goals. Through these activities, ECE helps the UN to identify frontier technologies and innovations critical for science and evidence-based implementation of the Sustainable Development Goals (SDGs).

A milestone in the period 2021-2024, was the contribution of ECE to the **IPCC AR6**. With no less than 17 Authors (Coordinating Lead Authors, Lead Authors, or Contributing Authors), ECE contributed to all major AR6 outputs of Working Groups I and III. This involved coordination of major scientific community efforts as input to the IPCC AR6 (e.g., the community model comparison on overshoot, ENGAGE), leadership of key chapters and sections in the Summary for Policy Makers, facilitating the collection of the scenarios for the IPCC, and hosting and curating the AR6 WGIII scenario data (Byers et al., 2022). These contributions offered comprehensive, policy-relevant insights that underpin the AR6's evaluation of climate mitigation and adaptation, including the AR6 Summary for Urban Policymakers, launched at the COP27 (Revi et al., 2022). From a scientific community perspective, it is important to emphasize that these assessments were made possible only through the coordination of major scientific community organizations, such as the Integrated Assessment Modelling Consortium (IAMC), and the ICONICS where ECE staff Bas van Ruijven, Volker Krey and Keywan Riahi serve as members of the Steering Committees.

Beyond the IPCC, ECE scientists (Matt Gidden, Shonali Pachauri, and Joeri Rogelj) were involved as Lead Authors and Steering Group members on the **UNEP GAP reports**. The reports provide a regular update on the progress of climate policy for the UNFCCC negotiations and identify critical policy gaps across sectors and regions. Furthermore, ECE staff, Lena Höglund-Isaksson, serves on the Scientific Oversight Committee of the **International Methane Emissions Observatory** (IMEO), and has co-authored the Global Methane Assessment (GMA) which informs the Methane Pledge of over 155 countries. Several ECE scientists have participated in related IPCC, UNEP, and other side-events at COP26, COP27, and COP28 explaining key insights of these reports to decision makers.

Through the **Network of Greening the Financial Sector (NGFS)**, ECE has been instrumental in developing climate and macroeconomic scenarios used by central banks and financial regulators to assess climate-related risks. By providing robust, science-based scenarios, ECE aids financial institutions integrate climate risks into their financial models, leading to better informed decision-making and robust risk management strategies. Specifically, ECE's work supports the NGFS in creating guidelines for climate stress testing. These tests are crucial for evaluating the resilience of financial institutions under various climate scenarios, promoting a more proactive approach to managing climate risks.

Policy impact at the European level comprised several influential reports by the European Advisory Board on Climate Change (EUABCC). ECE scholars Joeri Rogelj and Keywan Riahi are

members of the EUABCC and coordinated the Board's advice to reduce greenhouse gas emissions by 90-95% in 2040. Subsequently, the European Commission followed the advice of the EUABCC in its proposal to the EU Parliament to adopt the "heroic" **2040 EU target of >90%.** ECE has also been part of the scientific backbone underlying the strategies that were laid out by the European Commission aiming to deliver the climate objectives of the European Green Deal, i.e., the so called **'Fit for 55' package**. Together with colleagues from IIASA-BNR, ECE provided the scientific foundation for assessing the non-CO_2 greenhouse gas emissions and mitigation options in the EU. ECE modelling tools were used to provide the 'Fit for 55' package with country-specific mitigation pathways for all the 27 EU countries.

Examples of EU high-level policy impact in the area of air pollution include the recent European Commission proposal for the revision of the Ambient Air Quality Directive**,** which is directly based on the modelling work done by the ECE GAINS team. ECE has further led the work on Clean Air Outlooks assessing whether the objectives of the National Emission reduction Commitments Directive (NECD) and the Zero Pollution Action Plan of the Green Deal can be achieved. This will be instrumental in the forthcoming review of the Directive in 2025. Finally, the EMEP Center for Integrated Assessment Modelling (CIAM) of the UNECE **Convention on Long-range Transboundary Air Pollution** was hosted by ECE in 2021-24, assessing the feasibility of the UNECE region to achieve further significant reductions of health impacts and biodiversity loss by 2040. This analysis supported the Executive Body decision to initiate the revision of the Convention's Gothenburg Protocol scheduled for 2024-26; CIAM is charged with providing scientific input to the process working closely with other scientific bodies of Convention, national experts and eventually negotiators of the revised Protocol.

On the national scale, ECE provided policy advice to many countries around the world, supporting government agencies as well as multilateral initiatives (e.g., the GAINS health impact assessments organized through the World Bank). Systematic co-design and capacity development on **national integrated assessment tools** were provided in 2021-24 in India, China, Pakistan, Lebanon, Egypt, Israel, Uzbekistan, Canada, and Australia. Important success factors for the national policy support are 1) the organization of regular training workshops; and 2) strategic collaborations where national government agencies (e.g., NITI Aayog in India) are brought together with local knowledge institutions, with IIASA-ECE serving as the external methodology and knowledge provider. Long-term ECE collaborators have been using the tools in various national decision-making processes, such as, Brazil (COPPE) where the MESSAGE modelling framework is now used for the quantification of Brazil's Nationally Determined Contributions (NDC) in the UNFCCC negotiations. ECE also provided dedicated support and established the **infrastructure for national modeling comparisons** in India and China. In Austria, the host country of IIASA, ECE researchers are co-chairing the **Austrian Assessment Report on Climate Change (AAR2).** The AAR2 is established after the IPCC model with support of the Ministry of Environment and brings together all important climate research institutions in Austria to provide the scientific basis for climate actions in Austria.

Supported by the **World Bank Pollution Management and Environmental Health (PMEH) Program**, ECE has developed holistic road maps for action in China, Vietnam, India and South Africa, which enables local authorities in these countries to develop comprehensive air quality management plans. This work has been recently extended to address regions in other countries within the Indo-Gangetic Plane airshed including Pakistan, Nepal, Bhutan, and Bangladesh. Through 2021-24, ECE has 1) continued to support the **International Energy Agency (IEA)** providing the air quality impact assessment of the IEA World Energy Outlook, and 2) collaborated with **UNEP** and policymakers and scientists in Cambodia, Thailand, and Indonesia in order to assess the costs of inaction on air pollution. The latter project identified, jointly with the respective countries' Ministries of Environment, national investment cases for action, and supported the development of better integrated, science-based policy measures in these countries.

Several activities provided **policy support at the city scale** informing urban air pollution strategies as well as broader urban development agendas. Successful examples include Keywan

Riahi's role in the Scientific Advisory Board of the City Council of Vienna where he is supporting the city in the design of the "Vienna Climate Law" and the implementation of its climate action plan. ECE is a key contributor also to the initiative between the German and Chinese authorities to design digital transformation strategies for four cities in China and Europe (Beijing, Ordos, Vienna and Helsinki). The project has been established directly upon the initiative of the President of the Environment Protection Agency in Germany (Dirk Messner), which will host its next meeting in July 2024 at IIASA.

The activities described above are only some examples of the policy impact of the Program. Further elaboration of policy relevant work is also summarized in the following sections that present the achievements and impacts of each of the individual ECE Research Groups.

4.1.3. Program budget and staff

From 2021 to 2024, the ECE's in-house research effort averaged 65.5 scientific person-months per year, supported by an annual budget of €4,850 million, approximately 71.4% of which was externally funded.

Table 4-1 ECE Overall budget and staff (2021-2023), including external/internal, personnel/non-personnel costs.

	2021	**2022**	**2023**
Total income	**4,383,333**	**4,734,442**	**5,432,260**
External Projects and Grants	2,904,638	3,499,781	3,984,168
Internal allocation	1,478,695	1,234,662	1,448,093
Total expenses	**4,010,491**	**4,308,714**	**5,326,431**
Program surplus	372,841	425,729	105,829
Total FTEs	**61.25**	**70.40**	**84.24**
FTEs scientific	54.39	62.52	76.01
FTEs non-scientific	6.86	7.86	8.21

Note: The budget for 2024 is pending for final allocations. Internal allocations for 2024 are in order of 1,160 million Euro.

ECE Staff (2021-2024)
Over the past three years, our team had more than 200 members, comprising full-time staff, research exchange scientists, guest scientists, and post-docs (see Annex A).

Externally Funded Projects (2021-2024)
The budget from the externally funded projects and grants increased from about 2,9 million in 2021 to almost 4 million in 2023. The funding sources are diverse, ranging from grant from the European Research Council to World Bank and Industry partners (e.g., Toyota). A high fraction from the budget comes from community projects funded by the European Union Horizon Program. The portfolio of projects are listed in Annex B.

4.2. Integrated Assessment and Climate Change (IACC)

4.2.1. Summary of achievement of goals and highlights

Traditionally, integrated assessment research has focused on climate change mitigation, but addressing mitigation in isolation without considering the many linkages that a transformation toward a low-carbon economy has for essentially all aspects of society and the environment. IACC's main goal is therefore to push the research frontier toward the development of pathways that cover many more aspects of sustainable development to ultimately increase their policy relevance.

To reach this objective, research in IACC focused on five broader research areas that have been identified in the 2021-24 Research Plan: (i) energy system and carbon management solutions, (ii) integration of climate change impacts and mitigation strategies, (iii) integration of circular economy strategies into mitigation research, (iv) integration of analysis across scales including national transformation and analysis, and (v) climate change scenario services and good open science practices. Improving the representation of social-science research has emerged as a cross-cutting topic across most of these research areas.

Energy system and carbon management solutions

The global energy system is in a transitional phase with fast-paced changes meaning that new knowledge gaps and challenges are being identified in short succession. IACC has tackled three of these novel challenges in our understanding of supply-side transitions leading to a more sophisticated understanding of the potential contribution of carbon dioxide removal, a better integration of novel energy storage technologies allowing for a more faithful representation of the potential role of variable renewable energy, and a trailblazing integration of institutional, governance and socio-cultural dimensions in the modeling of energy system futures.

Traditionally bioenergy with carbon capture and storage (BECCS) has been the key energy system-based carbon dioxide removal (CDR) option considered in transformation pathways. This has been extensively criticized in the literature. Broadening the portfolio of CDR options, most notably under ERC synergy grant GENIE (Co-PI: Keywan Riahi) has thus been a focus of IACC research. To date, different variants of Direct Air Carbon Capture and Storage (DACCS) and options in chemicals production in the industry sector have been added to the IAM framework and analyzed in terms of their potential contributions to carbon removal (Gidden et al.,2023; Unlu et al.,2024). Further options that allow storing carbon in the built environment, including carbon-negative cement, wood-based construction, and the usage of bio-based materials are currently being explored. In addition, improving the comparability between land-based carbon fluxes of IAM projections on the one hand and national greenhouse gas inventories and stated emission targets based upon them on the other hand has also been in focus (Gidden et al.,2023b). This work reveals that achieving the benchmarks of IAM-based pathways as assessed by the IPCC is more challenging than suggested by a naïve comparison with the stated pledges of countries under UNFCCC. These improvements allow exploring alternative configurations of the undisputed need for CDR to achieve the Paris goals, taking into account local deployment constraints and societal acceptance of the different options.

With variable renewable energy sources such as solar photovoltaics and wind turbines having successfully scaled up over the past decades, system integration constraints have become a major concern for a successful transformation. Identifying and analyzing **novel energy storage technologies** as an alternative to well-known storage options to enable renewable energy futures has been another focus area of IACC. This is complemented by assessments of renewable resource potentials and detailed power systems modeling (Hunt et al.,2021, 2022, 2023, 2023, 2024, Weber et al.,2024) to address systems integration questions (see section on integration across scales below).

Global transformation pathways are most directly useful to policymaking if they adequately **represent the institutional, governance and socio-cultural dimensions** of the energy

systems transformation. To this end, social science insights about the feasibility of specific transformations (developed by TISS researchers (Brutschin et al.,2021)) have been incorporated in global scenarios based on MESSAGEix-GLOBIOM and other IAMs (Bertram et al., accepted, Brutschin et al., in preparation). As a result, pathways not only become more realistic but also more equitable as institutional capacity in countries of the global south limits the speed at which the transformation can happen, which is traditionally not represented in IAMs.

Integration of climate change impacts and mitigation strategies

Integration of climate change impacts into the integrated assessment of climate change remains essential to appropriately reflect the main benefits of mitigation (through avoided climate change impacts) and design strategies that are resilient in a changing climate. To better understand how climate impacts will affect different parts of the population, specifically taking into account the aspects of vulnerability and equity and the degree to which affected population segments are able to adapt, research has focused on quantifying the benefits of mitigation. Such a quantification requires an understanding of both the risks of climate change impacts and extremes through a range of suitable impact indicators (Werning et al., 2024) and the vulnerability and adaptive capacity (based on social science research) of those exposed to the physical impacts (Andrijevic et al., 2023). Risk emulation to rapidly assess the former is key for its integration into IAMs. The Rapid Impact Model Emulator (RIME, Byers et al., in preparation) delivers this. Important applications in this area that combine **risk emulation and risk assessment** include the implications of climate change for cooling energy needs in the buildings sector (Byers et al., in review), and the interaction of climate change impacts and mitigation action related to a broader set of sustainable development objectives related to water, energy, food, and land resources (Awais et al., 2024, Falchetta et al., 2023, Vinca et al., in review). Ongoing research also includes integrating the latest insights of econometric studies on economic climate change impacts (Kotz et al., 2024, Waidelich et al., Burke et al.) into IIASA's MESSAGEix-GLOBIOM framework to overcome the current limitation of most mitigation studies that macro-economic GDP and consumption estimates show higher losses under stringent mitigation compared to pathways without significant mitigation efforts (Vinca et al., in preparation). IACC is expanding the research in this area, also in collaboration with other research groups at IIASA (IBF, MDM, SYRR, and the newly established ICI group within ECE), and leads the SPARCCLE project.

Integration of circular economy strategies into mitigation research

The production of energy-intensive materials is responsible for about 25% of global GHG emissions. A new research area that was started with the establishment of the IACC group is the integration of energy and material flows in the IAM framework to broaden the strategy space beyond classic energy- and land-based climate mitigation strategies to include **circular economy approaches**. Initially, the research focused on bulk materials such as steel, cement, aluminum (Pedneault et al., 2021) and base chemicals including ethylene, propylene, methanol and ammonia for which production and recycling options have been integrated into a new industry sector module called MESSAGEix-Materials (Unlu et al., 2024). Looking at circular economy options beyond recycling, e.g. by utilizing material stocks more efficiently via sharing and service-based approaches and lifetime extension is a key objective of the research in IACC. Therefore, linking the demand for materials to key energy services such as shelter (Wang et al., 2022, Streeck 2022) and mobility (Virag et al., 2022) is work in progress together with the S^3 and TISS groups, exploiting synergies with the EDITS network (Sugiyama et al., 2024, Wiedehofer et al., 2023). Including acceptance of circular economy approaches both on consumer and producer side based on social-science research conducted under the CircEUlar project led by IACC is currently under way. Another ongoing stream of research is to include important critical metals for key low-carbon technologies, such as batteries, solar PV cells or wind turbines.

National transformation and methodological advancements to integrate analysis across scales

To help decision-makers at regional, national and subnational levels to understand requirements to align with global climate goals, the **integration of analysis across different spatial scales** has been a research focus relevant to all the previously described activities of the IACC

Group, requiring further methodological development. Key aspects of this challenge are on the one hand, increasing the spatial and temporal granularity of relevant parts of the IAM framework, and on the other, explicitly representing policy options at those levels, e.g. at the national or subnational scale. With respect to spatial resolution, a national model prototyping approach has been developed, which allows creating national or regional standalone models. This approach has been successfully demonstrated or is in development for Australia (Li et al., 2023, Kikstra et al., 2024), Canada (Awais et al., 2021), the central Asia region (Zakeri et al., 2022), China (Liu et al., 2022), Egypt, the Indus basin (Awais et al., 2022), Israel (Palatnik et al., 2021,2023), India, Lebanon, Pakistan (Mansoor 2024), the UNECE region (UNECE 2022), Uzbekistan, and Zambia (Awais et al., 2024).

Where finer scale information is critical for decision making as, for example, in the case of managing water resources, which at least requires hydrological basin representation in the decision-making process, the MESSAGEix-Nexus model (Awais et al., 2024) has been developed. The approach is scalable and has been applied at country and basin-level (e.g., Zambia, Indus basin) as well as at a global scale (Awais et al., 2022, 2024).

Another key example where bridging scales in decision-making is critical is air quality with a strong dependence on the energy system configuration but requiring high spatial resolution to understand exposure of humans and the environment to concentration of air pollutants. This is addressed by **linking MESSAGEix to the GAINS model** (see PM section). Applications of this include cases stretching from city (Beijing, Liu et al., 2022) to global scale (Rafaj et al., 2021).

High resolution assessments of geospatial data form the basis for modeling approaches that can be applied at different regional scales. Machine-learning based approaches to generate such datasets are actively being developed in IACC, for example to assess renewable energy potentials (Joshi et al., 2021, 2024).

Beyond spatial resolution, increased temporal resolution has also become vital to assess the viability of increasing the share of variable renewable energy sources and utilize load management options in IAMs. Linking MESSAGEix-GLOBIOM to power systems models (Brinkerink et al., 2022, Gotske et al., in preparation) has generated further insights on the level at which renewable energy sources can be utilized in the transformation to a net-zero GHG emission energy system.

Climate change scenario services and good open science practices

Finally, IACC is committed to **a full-fledged open science approach** with the MESSAGEix model, and its components being made available under open source and open data licenses (Fricko et al., 2023, Kishimoto et al., 2024). The different components of the IAM framework are developed in a modular way to allow for flexibility in adoption for different use cases but also reduces maintenance and potential lock-in. Sharing of the modeling tools is accompanied by community and **capacity building activities** to broaden the user base, in particular in IIASA member countries, and ultimately the decision-making impact of research. Since 2022, IACC annually organizes a MESSAGEix community meeting in hybrid format to engage with users of the modeling tools outside of IIASA, sharing use cases, latest developments and experience with the modeling framework. The meeting is attended by some 25 participants in person and a further 40-60 participants remotely. In addition, IACC is conducting regular training workshops on MESSAGEix for YSSP participants, external collaborators and other interested. A recent example includes a workshop held in Addis Ababa in October 2023 with 30 participants from 14 Sub-Saharan African countries.

Also, other software tools that are primarily developed in IACC and allow efficient use and handling of IAM-related data, such as the Python package pyam (Huppmann et al., 2021), are open source tools and have been adopted by a wide user community with in some cases tens of thousands of installations. Beyond making its own software tools and data openly available, ECE/IACC has positioned itself as a **community data hub for global climate change mitigation and transformation pathways**, for example, by hosting datasets for the IPCC's

AR6 (Byers et al., 2022), the IAM community, such as related to the Shared Socioeconomic Pathways, or for the finance community (Richters et al., 2023). These community data services are complemented by the development and maintenance of tools that disseminate and such as the IIASA Scenario Explorer as an expert tool and the Climate Solutions Explorer, a tool aimed at the scenario user community.

IACC Highlights of scientific output and policy impact

IACC research has systematically explored **the role of temperature overshoot and negative emissions** (Riahi et al., 2021), thereby informing IPCC reports and the UNFCCC climate negotiations. Up until then, most studies have focused on the distant future, requiring only that the temperature goals of the Paris agreement are achieved by the end of the 21st century. Consequently, almost all the resulting scenarios allow global temperature to overshoot around mid-century, only later turning the dial back down again by sequestering carbon from the atmosphere. The scenario design pioneered in Rogelj et al., (2019) has been rolled out to a larger set of IAMs, generating robust insights on the costs of temperature overshoot (Riahi et al., 2021) that has shaped key insights of the IPCC AR6 (Skea et al., 2022). In the meantime, this scenario design has become a de facto standard in the IAM community, used by dozens of studies.

The **climate scenario services** developed and provided to the research and policy communities by IACC have set new transparency standards, highly improving reproducibility of scenario analysis and enabling dozens of follow-up studies. The AR6 Scenario Explorer (Byers et al., 2022) that provides access to more than 3000 global, regional, national and sectoral scenarios, underpinning key insights of the IPCC AR6, and the NGFS Scenario Explorer (Richters et al., 2023) that is highly utilized by financial sector analysts to evaluate the transition risk of financial assets (cf. S^3 highlights) are key examples of IACC's policy impact, in addition to hosting dozens of other open scenario datasets. To complement the publication and hosting of key community datasets, the MESSAGEix-GLOBIOM IAM has been made available as an open-source tool (Fricko et al., 2023, Kishimoto et al., 2024), along with the newly developed Materials (Unlu et al., 2023) and Nexus modules (Awais et al., 2023).

With variable renewable energy sources such as solar PV and wind turbines having successfully scaled up over the past decades, system integration constraints have become a major concern for a successful transformation. IACC has focused thus on identifying and analyzing **novel energy storage technologies,** such as gravity storage systems (in lifts, mines and on mountains), buoyance storage systems, or deep ocean storage based on compressed air and/or hydrogen (Hunt et al., 2021, 2022, 2023, 2023, 2024, Weber et al., 2024). Many of these technologies can provide an alternative to currently available storage options, thus enabling renewable energy futures. Beyond the impact in the academic literature, these solutions also get implemented by companies as a new business model that facilitates the transformation towards a renewable-based energy system.

By **combining geospatial information with machine learning approaches** (Joshi et al., 2021, 2024), new high-quality datasets create novel analysis opportunities, increasing their relevance and timeliness. As a first application, the method is applied to roof-top solar PV potential. Mitigation scenarios to contain global warming to below 1.5ºC envisage a significant role for solar PV, but they are often very limited in evaluating the role of decentralised rooftop solar PV within the solution space. This gap has been addressed with the MESSAGEix model and scenario analysis, showing that by 2050 rooftop PV can account for >50% of total solar PV generation, thereby significantly reducing the land footprint of PV deployment. An assessment for Europe (Göke et al., 2023) using the methodology and data showed that available rooftop area would suffice for generating the annual demand of the EU27 by 2030.

Taking **adaptive capacity** as a key concept into account in studies that assess climate change impacts and opportunities to adapt to it has been an important contribution of Andrijevic et al., (2023). Global models that assess the impacts of climate change and policy options to reduce

them most often do not elaborately represent adaptation. When they do, they rarely account for heterogeneity in societies' adaptive capacities and their temporal dynamics. The study proposes ways to quantify adaptive capacity within the framework of the SSPs that are widely used by climate impact and integrated assessment models. A related ECE community service in this area is the SSP Extensions Explorer, which gathers adaptative capacity and numerous other quantitative extensions of the SSPs in a central database for easy use by the research community.

4.2.2. SWOT analysis of IACC

Strengths	Weaknesses
The scientific staff is the biggest asset of IACC. The strategy has been to have a balanced mix of senior researchers with the experience to position the group in promising new and impactful research areas, and a generally young interdisciplinary team, bringing in new ideas and cutting edge methods. Combining knowledge across different disciplines, in particular integrating social science research into integrated assessment both through in-house expertise and external collaborations is a major asset of IACC. The broad set of cultural backgrounds of IACC staff is also an advantage when integrating national, regional and global analysis. The development of new research proposals is handled in an inclusive way, offering young and mid-career researchers the opportunity to shape the future research direction of the IACC group and develop skills related to proposal writing and grant acquisition. This environment allows mid-careers researchers to develop experience and a scientific track record, creating career opportunities within and outside of IIASA. The latter ultimately leads to broadening the group's scientific network and opening new opportunities for collaboration. IACC has been very successful in raising external funding in support of its research activities with a proposal success rate well above 50%. Currently IACC is part of an ERC synergy grant (GENIE), and is leading two large collaborative EC funded Horizon projects (CircEUlar, SPARCCLE), and is participating in many other externally-funded high-impact activities, such as the new Earth Fund Project to establish a new climate scenario compass facility (CSCI). IACC has become the place to go for open science services, hosting key datasets on behalf of the IAM community and by making its own IAM framework available as an open-	Resources required to maintain and develop data-intensive large-scale models and tools (e.g., MESSAGEix IAM framework, Scenario Explorer infrastructure) could lead to lock-in and reduced agility when it comes to the adoption and development of new methods. The modular structure of IAM framework and other tools is an attempt to allow easier and more targeted maintenance to reduce the risk. Also, the wide-spread diffusion of artificial intelligence-based methods and big data applications could become a threat if the opportunities offered by the adoption of these methods are not adequately integrated into IACC's research portfolio. Currently, machine learning methods are used for processing large spatially and temporally resolved datasets as input for the IAM framework, an activity that is planned to be scaled up and expanded.

source tool. The Scenario Services and Scientific Software team as part of IACC enables the adoption of high quality standards in tool development and open data. IACC is thus well positioned and prepared for an environment where funders and users of the research demand full transparency, reproducibility and enabling reuse of the research along all dimensions.	
Opportunities	Threats
High resolution data on energy, climate, and environment is increasingly becoming available and has the potential to significantly improve the foundations of integrated assessment modeling by adopting data-driven modeling approaches. An example in this direction are the machine learning methods used by IACC researchers to estimate renewable energy potentials. Close collaborations with other research groups and programs at IIASA, including S^3, TISS, and POPJUS, have helped to bring social sciences into a new generation of integrated assessment modeling. The resulting policy advice and mechanisms (e.g., incentives) can be tailored to the needs of different socio-economic groups, thereby increasing policy effectiveness and resource efficiency to achieve overarching societal goals.	The large fraction of external funding makes strategic development of research activities challenging. While the acquisition of external funding is the responsibility of the research programs and groups, IIASA lacks a mechanism of reliable "banking and borrowing" of internal budget to buffer fluctuations in the success rates of external funding proposals. With the increase of societal relevance of IACC research topics over the past decade, also external funding opportunities from different funders (public, private, foundations) have increased significantly which has led to steady but sustained growth of IACC. As a result of no reliable reserves at the group level, temporarily declining external funding sources would translate into a loss of staff members which, combined with the need for maintaining large-scale datasets and models would reduce competitiveness. With the mainstreaming of energy and climate related research, commercial entities have increased and continue to increase activity in applied systems analysis, particularly for highly visible activities such as the hosting and dissemination of community datasets and compete for external funding sources.

4.3. Pollution Management (PM)

4.3.1. Summary of achievement of goals and highlights

Solving immediate and near-term environmental problems (ecosystems collapse, health impacts from pollution) and social problems (widening inequality gaps) in a cost-effective manner is an important step in enabling challenging, but indisputably needed, long-term transformations toward a sustainable world. Understanding such multiple benefits and their distribution across different groups in society could also enhance public support for these transformations.

While in the past the work of PM group had a strong air pollution and non-CO_2 GHGs focus, this is not sufficient to adequately address the current and emerging needs of society and policymakers. To address that, the PM group defined goals for the 2021-24 period, aiming to expand its focus toward the development of new approaches for multi-sectoral policy interventions to manage pollution across different media (air, water, soil) at various scales

(global, regional, urban/rural), and further develop understanding of mitigation potential for non-CO_2 GHGs. The key achievements supporting meeting the goals and objectives of PM group in 2021-24 include:

Supporting evaluation and development of air quality and climate policies

Two major contributions supporting review and development of **EU air quality policies** included (i) 2nd, 3rd, and ongoing 4th Clean Air Outlook that assess the prospects for achieving the objectives of the National Emission reduction Commitments Directive (NECD), Zero Pollution Action Plan, and provide input for the review of the NECD scheduled for 2025, and (ii) modelling work underpinning the proposal for revision of the Ambient Air Quality Directives that align more closely with the latest recommendations of the World Health Organization and required further development of the GAINS model to enable fine scale analysis for NO_2 and $PM_{2.5}$ (Denby et al., 2024). Preparing for harmonization of legislation with the EU, PM team held national consultations and employed GAINS model to calculate preliminary emission reduction commitments for Republic of Moldova and West Balkan countries, within the EU funded project EU4Green. For the **EU climate policy**, GAINS model provided analytical input, i.e., assessment of mitigation potential and costs for non-CO_2 GHG underpinning the European Green Deal – see also next section (Highlights).

In December 2023, the Executive Body of the UNECE Convention on **Long-range Transboundary Air Pollution (LRTAP)** initiated the revision of the Gothenburg Protocol, setting new and more ambitious targets addressing health impacts and loss of biodiversity due to air pollution. PM group (hosting the Convention's EMEP Center for Integrated Assessment Modelling (CIAM)) provided essential assessments during the review of the Protocol, evaluating feasibility of the new ambition, and will support preparations and eventual negotiations of the new Protocol in the period 2024-26. Addressing objectives of the Protocol, has required development of new methods for simultaneous analysis and optimization for mitigation of impacts on health, crops, ecosystems (including loss of biodiversity) as well as addressing equity considerations. The newly extended and updated GAINS capacity to address mercury emissions (Brocza et al., 2024) has been already supporting discussion within the Minamata Convention.

PM group has continued providing air quality impact assessment for the **World Energy Outlook** reports of the International Energy Agency. Supporting **Arctic Council** in development of the Arctic Monitoring and Assessment Program report (AMAP, 2021), analysis with the GAINS model underpinned results of the studies showing that well-designed air quality policy could help slowing Arctic warming (von Salzen et al., 2022; Whaley et al., 2022) and that managing forest fire risks in the Arctic will become increasingly important (McCarthy et al., 2021). PM scientists co-developed the Summary for Policy Makers that was presented at the 12 Ministerial meeting.

Air pollution and public health in Asia

Air pollution has been a major issue in Asia, contributing to severe health impacts and economic costs. The World Bank **Pollution Management and Environmental Health** (PMEH) program has developed jointly with PM researchers a systematic road map for action that should enable local authorities to develop comprehensive air quality management (AQM) plans for their respective regions. The GAINS model has been extended, evaluated and applied to specific regions in China, jointly with the Chinese Research Academy of Environmental Sciences (Shu et al., 2022, 2023), and Vietnam (Hanoi) and supported development and validation of inventories and policy scenarios to achieve compliance with national air quality legislation. In 2023, the World Bank, in collaboration with PM researchers published the South Asia Flagship study **Striving for Clean Air,** highlighting the critical role of interjurisdictional cooperation within airsheds in achieving clean air targets in a cost-effective manner. Building on the PMEH and the flagship study, PM group, jointly with the scientists from Indian institutions (including IIT Delhi, IIT Kanpur, State Pollution Control Boards), supports the World Bank and the Central Pollution Control Board, to further **develop and evaluate the AQM plans in the Indo-Gangetic Plane** states/regions. This work has been recently extended to address regions in other countries within the same airshed including Pakistan, Nepal, Bhutan, and Bangladesh.

Air pollution in often perceived as an urban issue, because the largest pollution levels are typically measured within cities. However, it is found that **in most cities a large share of $PM_{2.5}$ originates from sources outside of the cities**. Coordination and cooperation among authorities beyond city boundaries is indispensable. PM group, supported by Ministry of Environment Japan (MOEJ), have been working to identify and assesses interdependencies between urban and rural air pollution and highlight the air quality benefits from regionally and internationally coordinated response action. This work required significant further development of the GAINS model, involving scientists from the Norwegian Met Office and Kyoto University; the results were presented at the 2023 Better Air Quality Conference, and papers are in preparation.

The joint work with collaborators in North East Asia focused on development of decarbonization scenarios and assessment of their impacts at different scales, from local and national to regional (e.g., Liu et al., 2022; Cai et al., 2021; Qin et al., 2021), understanding role and trends of key pollution sources (e.g., Kanaya et al., 2021), and addressing secondary organic aerosols by applying an innovative approach to provide first such assessment at the global level (Huang et al., 2023).

Advancing understanding of sources and mitigation opportunities for non-CO_2 GHGs
The PM group has contributed to strengthening the knowledge about **methane** and its mitigation along several avenues: by contributing bottom-up emission estimates as prior to inverse modelling analysis (Naveen et al.,2024; Petrescu et al.,2023, 2024; Zhang et al.,2021), by co-authoring the Global Methane Assessments (UNEP, 2021; 2022), which provided the scientific basis for the Global Methane Pledge, and by providing non-CO_2 GHGs scenarios and mitigation potential underpinning Green European Deal (Höglund-Isaksson et al., 2023). Other achievements include contribution to the UNEP Gap Report (UNEP, 2021), the IPCC WGIII (Babiker et.al., 2022), and a perspective on the urgency of methane mitigation (Shindell et al., 2024; accepted). Among key resources supporting the methane Pledge is the International Methane Emissions Observatory (IMEO) with PM staff, Lena Höglund-Isaksson, on the IMEO Scientific Oversight Committee.

GAINS includes now an integrated representation of the waste and resources sector enabling consideration of the **interlinkages between greenhouse gas emissions, air pollution, water contamination, and material circularity** (Gómez-Sanabria et al., 2022; Gómez-Sanabria and Lindl, 2024; accepted) and will be extended to address plastic pollution (e.g., Brahney et al., 2021). The updated model has been used supporting EU climate policy work ('Fit for 55' package), sustainable waste management policy in South Africa (Gómez-Sanabria and Hoglund-Isaksson, 2023), and is currently assisting the government of Uganda to develop the strategy to reduce short-lived climate pollutants from the organic waste sector, which will be included in the next update of the Nationally Determined Contributions (NDCs).

The GAINS model enables a **comprehensive assessment of F-gas emissions** at high source, region, and species (HCFCs/HFCs, PFCs, SF_6, and NF_3) resolution and identify cost-effective management strategies, a unique approach not widely used by other modeling teams. The model now incorporates recently implemented regulations (regionally and globally) and approved commercialized alternative low-GWP refrigerants and abatement technologies for various applications and has served as scientific basis supporting revision of the EU climate policy ('Fit for 55' package) and contribution to the forthcoming report on Life Cycle Refrigerant Management. The recent contribution to discussion of global mitigation potential for F-gases is included in the 'Highlight' section below.
Integration of multiple nitrogen sources, compounds (NOx, NH_3, and N_2O), and diverse impacts in GAINS allows to adopt a "**nitrogen lens**" and **capture co-benefits of measures** across several pollution domains/dimensions. GAINS work contributed to the revision of global N_2O budget for the Global Carbon Project (Tian et al., 2024, in press) and improvements in bottom-up modelling (Del Grosso et al., 2022; Cui et al., 2024). Focusing on primary N_2O mitigation, soil inoculation with N_2O consuming bacteria was investigated (Hiis et al., 2024) offering an entirely new and innovative mitigation opportunities, and low-cost options in chemical industry were

revealed (Davidson and Winiwarter, 2023). On the air pollution side, detailed studies on NH_3 emissions (Adalibieke et al., 2021) led to quantification of the effect of different abatement strategies on adverse health impacts of particulate matter, specifically considering the role of NH_3 and NOx (Gu et al., 2021). A shift in the chemical regimes of PM formation over time and space also needs to be considered as it affects efficacy of respective nitrogen strategies (Liu et al., 2023). Innovative work analyzing reactive nitrogen flows in urban areas (Kaltenegger et al., 2023) combined with GAINS mitigation scenarios, will form a core contribution to the International Nitrogen Assessment (see www.inms.international), a major compendium of the global advancements of nitrogen research scheduled for publication in 2025.

Sizable cuts in anthropogenic methane emissions within the next decades is one of few options available for constraining near-term warming and avoiding the profound risks of temperature overshoot in the next few decades. ECE program research groups work closely together to **maximize synergies between the modelling tools in the ECE program** and operationalize dynamic and flexible links between the models, especially GAINS and MESSAGEix. These joint efforts lead to more robust projections of non-CO_2 GHG in global assessments but also enables analysis and comparison of several health and ecosystem impact indicators for MESSAGEix (and in the future other global IAMs) produced scenarios, including forthcoming new SSPs, where GAINS provides for appropriate source, spatial, and temporal resolution. This works includes also parameterization of air pollutant emissions and has been initiated under the Horizon project CD-LINKS and continues, supported by OPEN-Entrance, ENGAGE as well as funding from Korea (AQNEA, GUIDE) and China's power grid company (GEIDCO).

Linking health impacts, equity, and climate change

Applying innovative decomposition methods, Rafaj et al., (2021) found that **population dynamics**, especially aging and urbanization, counteract in many regions the mortality reductions due to declining emissions; also Conibear et al. (2021), using GAINS model scenarios, have shown similar results for China. In another study focusing on India, Rao et al., (2021) showed that **pollution burden is generated by the wealthy**, while the poor suffer most of the health impact. PM researchers have critically contributed to the Lancet Countdown **introducing an indicator for mortality from ambient air pollution by economic sector**. The changing climate has already affected and worsened several indicators of ecosystem and human health, disproportionately affecting populations who have contributed least to the problem (Watts et al., 2021). A third of the premature deaths attributed to anthropogenic sources of ambient air pollution in 2019 was directly related to fossil fuels exposing the **costs of the delayed decarbonization and air quality regulation** (Romanello et al., 2021). In another contribution, Hamilton et al., (2021) conclude that a greater consideration of health in the NDCs and climate change mitigation policies (addressing air pollution, diets, physical activity) has the potential to yield considerable health gains as well as bring additional climate benefits – these are further analyzed for the EU under the Horizon Europe project CATALYSE where GAINS model is employed to develop scenarios reflecting on impacts of active mobility and dietary change.

Quantifying the **cost of inaction on air pollution** could help building stronger investment cases for action and support the development of more integrated, science-based policy providing benefits for health, climate, and sustainable development. Through 2021-23, PM researchers have engaged with UNEP and policymakers and scientists in Cambodia, Thailand, and Indonesia to assess cost of inaction on air pollution evaluating respective evidence and assessing feasible mitigation strategies building on the 'Clean Air and Climate Solutions for ASEAN' study, where modelling was led by PM group (CCAC/UNEP, 2024; in press). Providing this analysis required adaptation and further development of the GAINS model expanding its capacity to include for the first time morbidity (Ru et al., 2023).

PM Highlights of scientific output and policy impact

PM research has contributed to the scientific backbone underlying the impact assessments of the European Commission aim to deliver the climate objectives of the **European Green Deal**. Phase-out of fossil fuel use is key to achieving climate neutrality, but it will not be enough unless a net zero balance in non-CO_2 greenhouse gas emissions and land-based CO_2 emissions and

sinks is also achieved. As part of a long-standing collaboration with other European modeling groups, PM's GAINS model has provided non-CO_2 greenhouse gas mitigation pathways at the country and sector level for EU's 27 countries, which along with land-use CO_2 pathways from BNR's GLOBIOM model, are used to ensure the scientific rigorousness of EU's climate policy strategies.

Using a novel decomposition approach, an PM led study on the **pollution-demography-climate nexus** highlighted impacts of population dynamics for the resulting health co-benefits of mitigation (Rafaj et al., 2021). The study finds that demographic processes, particularly aging population, but also urbanization, counteract in many regions the mortality reductions realized through lower emissions and consequently declining pollutant concentrations. Building on this work, the Lancet Countdown studies use now an indicator for mortality from ambient air pollution by economic sector, introduced by PM researchers who regularly contribute to Lancet (Watts et al., 2021; Romanello et al., 2021, 2023; Hamilton et al., 2021; Zhang et al., 2023; van Daalen et al., 2024). PM research shows that contrary to common beliefs and often implemented policies, in most cities a large share of $PM_{2.5}$ originates from sources outside of the cities.

Some of the climate and air quality co-benefits offered by **circular waste management** systems are poorly understood. We developed the first global assessment of emissions and mitigation potential from such systems for SSP-consistent scenarios, considering urban and rural distinctions (Gomez-Sanabria et al., 2022Gomez-Sanabria et al., 2022). Recently, spatial analysis was integrated to the analysis to quantify waste leakage into aquatic environments (Gomez-Sanabria and Lindl, 2024; accepted). Insights from this work and in-house expertise contributed to the Global Waste Management Outlook (UNEP, 2024). These advances expand the analytical capacity and application scope of the GAINS model, enabling better representation of this sector in the global integrated assessment models.

Limiting growth of F-gases emissions has been a priority, underscored by the Kigali Amendment to the Montreal Protocol. However, stronger international action to reduce HFCs are necessary to align F-gases emission trajectory compatible with Paris Agreement goals and increase the chances of limiting global warming to 1.5°C (Purohit et al., 2022) while further mitigation can be achieved by switching to low-GWP refrigerants, such as propane (Purohit et al., 2022). Furthermore, understanding the ecological and human health implications of some HFC alternatives has important implications on policy and industry towards development and application of safe and reliable low-GWP alternatives (David et al., 2021).

PM group, hosting the EMEP Center for Integrated Assessment Modelling (CIAM), supported **review of the Gothenburg Protocol** to the UNECE Air Convention (the first multipollutant-multieffect international agreement) playing a key role in providing evaluation of progress in achievement of its objectives and exploiting potential for future steps. New GAINS model analysis, performed in collaboration with other scientific bodies, national and international stakeholders within the Convention, assessed implications of introducing collective risk-based targets for the UNECE region (including Europe, Central Asia, and North America) to address air pollution impacts on health and ecosystems, including risk of biodiversity loss. In December 2023, drawing on this analysis, the Executive Body of the Convention decided to start the revision of the Protocol - work scheduled for 2024-2026.

4.3.2. SWOT analysis of PM

Strengths	Weaknesses
In our view, one of the main **strengths** of the PM group is its international and interdisciplinary team of scientists that continue providing insights and guidance to policymakers working at local, national, regional and global scale addressing human and societal wellbeing and emerging environmental challenges. The innovative perspectives developed by the team are now shaping scientific thinking and regional and global policy processes on multi-pollutant/multi-effect approaches to the management of air pollutants and non-CO_2 greenhouse gases, including focus on short-lived climate forces (e.g., black carbon, CH_4) and co-benefits of measures for different policy objectives. Building on the trust and credibility (also because of open access model tools) established within the EC and UNECE policy community, PM group expanded its scope interacting and supporting World Bank, UNEP, CCAC in Asia, Africa, and globally making PM a reliable and attractive collaboration partner for other scientific organizations and policy outlets. Over time, the group has been very successful in strategically using IIASA's institutional contributions, also capitalizing on the interactions and capacity within the ECE program, to leverage additional financial resources and enhance its scientific capacity through a large network of collaborators around the world.	There are challenges to overcome some of our perceived **weaknesses**, including increasing resource need to maintain and keep up-to-date large-sale datasets and modelling infrastructure of the GAINS model. Not addressing this challenge might lead to delays or lack of capacity to develop and implement new methods and extend tools to address emerging issues. We also perceive the simplified representation of systems dynamics in the current GAINS framework as another (theoretical) weakness, although it has arguably facilitated the understanding and acceptance of GAINS results by decision makers. However, a proper representation of the dynamics (e.g., from long-lived infrastructure) while maintaining transparency and manageability of the entire system is at the core of our current research agenda. Finally, employment of machine learning tools, for example to improve spatial distribution of emissions, downscaling of activity projections, and error detection needs further attention.
Opportunities	**Threats**
While the new program/group structure and retirement of few critical PM staff members brought some threats, we have seen those also as an **opportunity,** bringing in new expertise into PM and explore the benefits of closer collaboration across the groups within the ECE program, especially with respect to better addressing the interactions across temporal and spatial scales, building links between GAINS and the MESSAGEix models, and analysis of links between wellbeing and pollution. This experience has been opening up further potential for work closer with the global integrated assessment community extending analysis capacity at both ends. The global implementation of GAINS with rich source and spatial detail offers the chance to contribute information on spatial heterogeneities to the science communities that address the evolution of emissions, atmospheric chemistry and climate at the global scale. Furthermore, there is wide scope for knowledge transfer on potential co-benefits and methods to harness synergies in a systematic way to scientists and decision makers in many world regions. In particular, the new feature of linking pollution levels at street level to the sources at different scales could provide a powerful instrument for local planners to reveal local benefits of larger scale interventions.	Finally, there are a number of potential **threats**. The vitality of different strands of work in the PM depends critically on the level of policy interest. Strong interests from the policy community helps to activate financial support and motivate international scientific networks to participate in the development of new tools and insights. Since preferences differ across the world regions, diversification of research lines, and in particular the inclusion of other types of co-benefits and policy priorities, could substantially reduce such threats. PM has been addressing these by extending the expertise in the team and further developing the model increasing its analytical capacity to address emerging issues. Increasing share of external funding and lack of internal 'banking and borrowing' of internal budget might lead to difficulties to buffer natural fluctuations in successful acquisition of such funding. This could result in challenges to retain scientific staff and maintain the modelling infrastructure that is already under 'funding pressure'. A rather important potential threat to the vitality of the research group relates to the ability to attract qualified young scientists. The competitiveness of IIASA's.

4.4. Sustainable Service Systems (S3)

4.4.1. Summary of achievement of goals and highlights

Traditionally, climate mitigation scenarios have often focused on supply-side mitigation measures, in which large-scale technologies provide a clean supply of energy. Such scenarios had little representation of energy-using behaviors and showed a limited need for changes in energy demand. The emergence of strong demand-focused scenarios (Grubler et al., 2018), initiated a renewed focus on the role of behavior and lifestyles and their potential in reducing environmental pressures.

To drive scientific progress in this area, the stated goals of the S^3 group for 2021-2024 included two main research objectives. First, to explore the evolution of people's behaviors and lifestyles in using services and goods that require energy and assessing their environmental impacts, and second, to identify and analyze policy interventions that can change behaviors and lifestyles to minimize environmental impacts. The research in S^3 focused on three domains that are critical for the sustainable transformation challenge: buildings, mobility, and consumer goods. Across these three domains, research in S^3 focused on two cross-cutting connections: infrastructures and lifestyles. Infrastructure developments in one domain influence the other domains, and the slowly evolving infrastructures provide the boundaries for individual behavioral choices. "Lifestyle" is the aggregate of behaviors that emerge across individual behaviors in different domains.

Beyond this focus, the research in S^3 also contains ECE's efforts to provide scenarios for the financial sector and to improve the representation of the financial sector in climate scenarios. Hence, major achievements to meeting the goals described above can be clustered in five key research areas:

Identification of policy interventions that capture the benefits of behavioral change.
Upon the outbreak of the COVID-19 pandemic, S^3 researchers developed global scenarios for behavioral change during the recovery from the pandemic (see highlight 1 below) and found that low-demand lifestyle changes would enable faster climate mitigation at lower costs (Kikstra et al., 2021). Policy insights from this study have percolated to the European Commission, and in IPCC AR6. S^3 researchers pioneered the development of detailed demand-side policy scenarios and implementing policies that represent avoiding, shifting, or improving the way households use energy in the buildings sector (Mastrucci, et al., in review) and found a mitigation potential for global residential space heating and cooling of up to 60% of CO_2 emissions in 2050 relative to 2015, enabling net-zero emissions when combined with supply-side measures. These scenarios have subsequently been taken up by the research community in multi-model studies (Kriegler et al., 2023) that confirm the novel insights.

S^3 researchers have also broadened the scope of policy options by expanding the types of scenarios to be analyzed. For example, the innovative Low Energy Demand scenario (Grubler et al., 2018) has been further deepened and detailed into concrete policy interventions in the High-with-Low scenario, showing how high wellbeing can be achieved with low energy and material resource consumption (Wilson et al., 2023, Niamir et al., 2024). Another example is the development of a local sustainability narrative with strong focus on wellbeing in collaboration with Japanese colleagues (Kamei et al., 2021). More recently, researchers from the S^3 group have been at the forefront of developing and implementing the first post-growth and degrowth scenarios in global and national integrated assessment models (Min et al., in review Kikstra et al., 2024).

New granular, sector-level, modeling frameworks that represent heterogeneity and behavior.
A major focus of S^3 researchers during the first years of the research group has been on developing new modeling frameworks that enable to analyze the pace, potential, and costs of demand-side climate policy measures and the climate and energy consequences of providing

basic needs to all. These new frameworks include descriptions of access to services, physical activity and infrastructures, efficiency and technology choice in the buildings and transport sectors with high socioeconomic and geographic granularity (Mastrucci et al., 2021, Poblete Cazenave et al., 2021). A fundamental review of the modeling needs to properly represent demand-side measures also highlighted the innovativeness of the S^3 modeling frameworks (Mastrucci et al., 2023).

The new modeling frameworks have allowed to us explore topics that could not be studied in the context of Integrated Assessment modeling before. For example, we showed that lifetime extension of buildings, switch to wood-based construction, reduction of per-capita floorspace, could reduce the demand for building materials in China by 60% compared to reference in 2060 (Mastrucci et al., accepted, Zhang et al., 2022). Novel datasets that expand global coverage of materials intensity further enable this research (Fishman et al., 2024). Finally, closing the cooling gap without strongly increasing energy use (Mastrucci et al., 2022, Andrijevic et al., 2021) and using cool roofs as adaptation measure (Nutkiewicz et al., 2022) could now be studied as well.

Methodological advancements and empirical analyses to understand and represent the role of social interactions and behavioral changes in future scenarios.
Researchers in S^3 have developed new methods to empirically identify the differences in energy and resource use between different lifestyle groups and, in collaboration with behavioral scientists, explored diversity in response to policy interventions (such as nudges or price-signals). These new empirical insights were turned into modeling frameworks and will help in the future to formulate effective and realistic demand-side policies. Jointly with Oxford University, S^3 researchers quantified behaviors of different lifestyle groups diverge with climate policies and found that this can lead to bifurcation in society between 'engaged' and 'disengaged' groups, and that these groups apply different measures to avoid, shift, or improve their energy use, depending on their available means (Pettifor et al., 2023). In another example, coupling an agent-based model with building stock modeling showed how information and peer influence helps to diffuse energy efficient behaviours (Niamir et al., 2024).

To meet the highly granular data requirements for this type of research, S^3 is also leading the explorative use of social media data as complementary data source to characterize heterogeneous behaviour in societal groups (Eker et al., 2021, Eker et al., 2023, Gaup and Eker, 2024)

Establishment of a global research community focusing on demand-side solutions to mitigation
Beyond IIASA, the S^3 group is also leading the establishment of a global research community on Energy Demand changes Induced by Technological and Social innovations (EDITS) . EDITS aims to strengthen the understanding of behavior, wellbeing, and resource use, to increase the evidence base for low energy demand scenarios and to better inform policy makers. Highlights of EDITS community research activities with strong ECE/S^3 involvement include a deep assessment of the state of science, as well as the modeling needs for quantifying low demand scenarios (Mastrucci et al., 2023, Wiedenhofer et al., 2024, Thomas et al., in review), laying out a research agenda to increase the evidence base for demand-focused scenarios in climate assessments (Sugiyama et al., 2024) and a study finding that demand-side measures are more beneficial for energy security than supply-side measures (Bento et al., 2024).

Pioneering the climate scenarios for financial risk assessment and the role of finance in IAMs.
Researchers in S^3 pioneered a novel avenue for policy impacts by working with the financial sector and developing new climate scenarios for financial risk assessment. This started with activities to visualize and explain insights from climate scenarios for financial analysts and collaborating with the UNEP Finance Initiative to guide commercial banks into the use of climate scenarios (van Ruijven and Min, 2020). Subsequent development of bespoke MESSAGEix-GLOBIOM scenarios for the Network for Greening the Financial System (NGFS), a group of 138 central banks and financial supervisors that use these scenarios for financial stress testing in their jurisdictions, including annual updates and releases, and the provision of downscaled IAM scenario outputs at the country level (Bertram et al., 2020, Bertram et al., 2021, Richters et al.,

2022, Richters et al., 2023) represents a major and direct impact of ECE research on financial decision making in the climate transition.

Complementary to these activities, researchers in S^3 worked to improve the representation of the financial sector in climate scenarios. By laying out a framework for including financial sector attitudes (Battiston et al., 2022) as well as providing a pioneering example (Al Khourdajie, et al., in prep.) we provide a constructive contribution to improving integrated assessment scenarios.

S^3 Highlights of scientific output and policy impact

- The publication by Kikstra et al., (2021) introduced a set of global COVID-19 shock-and-recovery scenarios, systematically exploring the lasting effects of demand changes. This paper in Nature Energy exemplifies a swift and impactful scientific response to the COVID-19 crisis, significantly enhancing the policy relevance of demand-side research. It compellingly demonstrated that integrating energy-efficient practices into new travel, work, consumption, and production patterns post-pandemic would alleviate climate mitigation challenges. This influential work has been discussed with policymakers and business leaders across the USA, Europe, Asia, and with the OECD, and was prominently cited in the IPCC AR6 to emphasize the potential impact of behavioral change on mitigation.
- Significant scientific progress has been made through the development of a holistic, interdisciplinary framework for buildings-related energy demand. This framework integrates stock turnover modeling (Mastrucci et al., 2021), detailed microsimulation of household choices on cooking energy and appliance ownership and use (Poblete-Casenave, 2021), and behavioral modeling on renovation decisions (Niamir et al., 2024). This comprehensive approach enables the analysis of a wider array of policy options in climate scenarios and marks a major advancement in providing critical information to policymakers.
- The innovative lifestyle simulation model by Pettifor et al., (2023) combines extensive empirical research from Oxford University with advanced model development at IIASA. This groundbreaking approach simulates low-carbon lifestyle heterogeneity and changes, enabling dynamic analysis of distinct lifestyle contributions to targeted mitigation strategies. The model reveals a significant gap between 'engaged' types, who achieve faster and greater reductions in final energy demand, and 'disengaged' types. Furthermore, drivers of lifestyle change vary across different actions, with 'disengaged' types responding more strongly to energy-saving behaviors.
- The scenarios developed by S^3 and IACC for the Network for Greening the Financial System (NGFS) significantly influence global financial decision-making. These scenarios are mandated for climate stress testing by 138 central banks and financial supervisors worldwide. In addition to the MESSAGEix-GLOBIOM scenarios, IIASA has pioneered an advanced method for downscaling IAM outputs to the country level and maintains the essential database backbone for this complex project and public outreach. The annually updated, bespoke scenarios for the finance sector have a rapidly expanding user base among financial consultancies, commercial banks, and financial supervisors.
- In June 2022, S^3 spearheaded the organization of the second Forum on Scenarios for Climate and Societal Futures at IIASA. Stepping up the leadership of ICONICS to create a global scenarios research community. This event united over 500 researchers from 33 countries, spanning climate science, impacts, adaptation, and mitigation research. They discussed ongoing scenario developments and applications, identified successes, and outlined necessary modifications and next steps for the community scenario process. By spearheading research community leadership, organizing webinars, meetings, and projects, IIASA decisively supports this emerging research community, driving progress and innovation in the field.

4.4.2. SWOT analysis of S3

Strengths	Weaknesses
The main **strength** of the S^3 research group are its highly motivated, experienced, and exceptionally qualified staff, whose expertise and dedication drive its success. This excellence is further enhanced by the group's robust interconnectedness with other research initiatives at IIASA and on the global scale. In recent years, the younger generation of S^3 research scholars has built a formidable reputation through groundbreaking research and community leadership. This rising cohort has significantly contributed to the group's achievements, with many currently moving into senior positions, spearheading the acquisition of funding, and mentoring early career researchers. The central, leading role of S^3 within the EDITS network has provided substantial opportunities for colleagues to refine their research and leadership skills. This prominent position has enabled them to implement ambitious research agendas in collaboration with renowned scholars, influence policy-making, and attract talented new staff. S^3 has secured a diverse array of research funding from a variety of sources, including international research funders, foundations, and businesses. This diverse funding portfolio underscores the group's broad appeal and capability to sustain and expand its innovative research endeavors. A third strength is the multidisciplinary, multi-faceted demand-side modeling framework that the group developed. The combination of models from engineering, economic, and social science traditions with high levels of granularity has the ability to respond to information needs from a variety of policy makers at the world, country and city levels.	The **weaknesses** of S^3 relate to the strong interconnectedness of demand-side research with many other research topics, such as energy supply, climate, social sustainability, equity and justice. This diversity of demands requires a careful harmonization of plans to respond adequately to the evolving needs of NMOs, stakeholders, or funders. While this flexibility to respond to new opportunities and research questions is fundamentally a strength of IIASA, it also places a significant burden on staff to adapt quickly and manage the risk of overcommitment. Additionally, the early stages of establishing the research group and modeling tools present another challenge. As the group transitions from the innovative and original model development phase to a focus on maintaining and updating more mature modeling tools, it faces the need for a stable and continuous funding environment. Model and data maintenance, while less rewarding to both researchers and funders, is essential for sustaining the ability to perform world-class research.
Opportunities	**Threats**
The primary **opportunities** for S^3 lie in its capability to meet the growing information needs on demand side solutions from policy makers, science funders, and scenario users. There is a rising demand for more granular, sectoral information in climate scenarios, which the S^3 group is well positioned to provide. Moreover, policy makers are increasingly interested in the evaluation of broader and more concrete policy measures in cities and for different sectors, and S^3 is well equipped to respond to these requests. Financial actors have a special interest in detailed sectoral information, even though this has yet led to translate to concrete funding for the S^3 research, catering effectively to these users would be an opportunity for the group. The emergence of new datasets on behavioral aspects of society provides another opportunity to structurally enhance the underpinning of demand-side research. To fully leverage this opportunity, however, investments in methodological development, data consistency, and data processing will be essential. These investments will enable S^3 to harness the full potential of these datasets, thereby strengthening the foundation of their research. Another opportunity is that S^3 has been spearheading the creation of a global demand-side research community in EDITS. Due to its strong ties and central leading role in this community, S^3 and has the opportunity to leverage benefits through well-designed collaborative studies with globally leading scientists to feed information needs related to its own research.	**Threats** for the S^3 research emerge from the strong dependence on external funding and the workload for staff. While the funding portfolio has a diversity in sources, the recent trends of high inflation and volatile exchange rates, combined with the lack of a banking and borrowing system for research programs at IIASA portrays a threat for the continuity of employment and development of the research group. These financial risks and the reduced employment benefits at IIASA also complicate an adequate response to the increased competition in attracting highly qualified researchers. Finally, many highly interesting opportunities for S^3 staff to contribute their impactful research to policy processes come without additional funding or capacity expansion. Consequently, the workload of staff is high and increasing, which is not sustainable for IIASA in the longer term and risks limiting its capacity to flexibly respond to future opportunities.

4.5. Transformative Institutional and Social Solutions (TISS)

4.5.1. Summary of achievement of goals and highlights

Efforts to address the environmental impacts of climate change have typically relied on centralized, large-scale technical solutions, drawing primarily from engineering, economics, and the natural sciences. Assessed using economic cost and efficiency-based criteria, such solutions often neglect social, institutional, and distributional aspects that are key for implementation. This calls for a more comprehensive and integrated approach to simultaneously meet developmental, planetary and public health, and wellbeing related goals.
In line with this call, the TISS Group's stated goals for the 2021-2024 period are to explore innovative solutions to environmental issues that integrate social, institutional and governance drivers with technological, and economic considerations, with an emphasis on improving conditions for the most deprived and marginalized in society.

Thus, the TISS RG emphasizes two focal areas in its research:
A systemic analysis of technological, social, and institutional innovations (including inter alia new business models, social entrepreneurship, and novel public policy designs) with a focus on end-use services for human wellbeing that minimize negative environmental impacts.
Integration of heterogeneity, governance, and diverse justice considerations in policy analysis and implementation under a broader framing of transformations towards more resilient and sustainable futures.

Major advancements across four key research areas are described below that have been fundamental to achieving the stated goals of the TISS RG over the last four years.

Global and regional analyses of multidimensional deprivations, pathways to ensure a decent life for all and improve wellbeing while respecting critical planetary processes.
Over the past four years, the TISS RG has made significant strides in conducting original global and regional analyses aimed at measuring multidimensional poverty and deprivations, and devising pathways that ensure a decent living standard for all while simultaneously minimizing environmental impacts. Through a multidisciplinary approach integrating methods from economics, industrial ecology, environmental and social sciences, and engineering, the TISS RG in close collaboration with the S^3 and IACC RGs have explored decent living gaps globally, as well as access to specific energy services such as cooking, cooling and other essential household end-uses that relate to fundamental human needs (Kikstra et al., 2021; Poblete-Cazenave et al., 2021; Pachauri et al., 2021; Zimm et al., 2022; Mastrucci et al., 2022; Virag et al., 2022; Ummel et al., 2024; Hoffman et al., 2024 under review).

Our work has contributed to the identification of key regions of the world and population groups facing multidimensional deprivations and insights on innovative interventions needed to enable the achievement of a decent life by all. In this effort, we have also undertaken processing, cleaning, and standardizing of household survey microdata from a series of developing countries to enable sub-national detailed analysis of access to decent living standards, energy consumption, and energy poverty. We are now also exploring how these factors intersect with sub-national climate vulnerability, to inform climate resilient development futures. Additional research has critically assessed the multidimensional benefits of improving access to fundamental energy services and decent living standards by leveraging advanced quantitative methods and data analytics (Falchetta et al., 2023; Pelz et al., 2023; Rao et al., 2021; Belmin et al., 2021).

Novel theoretical frameworks and practical tools to assess and incorporate equity, fairness and justice concerns in transition scenarios and analyses.
To weave equity and fairness into climate scenarios, the TISS RG has developed a series of innovative tools and analytical frameworks grounded in philosophical principles and the effort sharing literature. The Fair Mitigation Finance Explorer, accompanying the paper 'Fairness considerations in global mitigation investments' (Pachauri, et al., 2022), is a web application that

allows users to explore 'fair' regional contributions to mitigation investment needs by selecting from various indicators linked to emerging fairness principles. This foundational work informed the European Scientific Advisory Board on Climate Change's advice to the EU on what a fair and feasible 2040 target for the EU could be (Pelz et al., 2023).

An award winning YSSP project led by PhD student Gaurav Ganti (Humbold University, Berlin) in 2023, outlines a framework to enhance the integration of equity in climate change mitigation strategies, addressing a gap noted by the IPCC. The work highlights the need for additional diagnostic scenarios to broaden the solution space enabling the consideration of a wider range of trade-offs across mandatory and optional normative fairness considerations in mitigation pathways linked closely to the textual elements of the Paris Agreement (Ganti 2023).

The development of the Carbon Debt Tool within the ELEVATE project offers stakeholders insights into carbon debt and credit projections, encouraging an intuitive understanding of 'fair' shares in carbon accounting post net-zero (Pelz et al., 2024 submitted). Our work on integrating carbon debt into the model protocol of a justice model intercomparison project (JustMIP), which we are co-developing, is a significant step towards embedding diverse justice considerations in climate modeling. Finally, a recent publication introduces a new justice framework aimed at influencing the next cycle of the IPCC scenario generation and related climate policy discussions and research more broadly (Zimm et al., 2024). Ongoing work also analyzes the distributive patterns implied in IPCC scenarios and is working with stakeholders via a tool to enlarge the scenario space capturing more diverse accounts of justice.

Research on the co-production of mitigation and sustainability scenarios with several stakeholders and policy actors, applying methods from systems dynamic modeling, is part of ongoing research in projects like WorldTrans. Methodological developments are also underway to improve the diversity and inclusivity of scenario generation processes by also incorporating voices of marginalized and indigenous communities.
These contributions are crucial to inform global discussions on equitable climate action and support stakeholders in navigating the complexities of climate mitigation strategies. We have also initiated efforts to actively engage with policymakers, negotiators, and other stakeholders to test our tools and ensure that our research is effectively translated into actionable recommendations and policies.

Methodological advancements and empirical analyses to evaluate the significance of governance and institutional factors in shaping the feasibility of transitions.
To support a better understanding of feasibility from a multidimensional perspective, TISS scholars have developed a new framework for ex-post scenario evaluation of outputs from Integrated Assessment Models (IAMs), which include, among other factors, considerations of institutional feasibility regarding the implied speed and scale of emissions reductions (Brutschin et al., 2021). The core of the framework uses insights from qualitative and quantitative studies of past transitions to deduce either the rates of change observed under the best-case scenario or the enablers of major advances in line with more ambitious transformations. This framework has been used by other scholars (Achakulwisut et al., 2023; Gidden et al., 2023; van de Ven et al., 2023) and discussed in Nature Climate Change (Pianta & Brutschin, 2023). It has also been modified and applied in the context of the EU advisory board (Byers et al., 2023).

Further developments of the framework have explored in more detail the drivers of a more ambitious coal phase-out (Brutschin et al., 2022), technology diffusion (Zimm, 2021), scaling up nuclear energy (Brutschin, 2021), and carbon dioxide removal (Gidden et al., 2023; Schenuit et al., forthcoming), with a strong focus on the role of governance and institutions in enabling or constraining these transitions. There have also been major efforts to advance the framework on how insights from the social sciences can be linked to global integrated assessment models in close collaboration with colleagues from the IACC RG (Brutschin & Andrijevic, 2022; Pianta & Brutschin, 2022, Andrijevic et al., under review).
Key contributions to improve our understanding of tipping points and safe and just earth system boundaries.

Scholars in the TISS RG have been supporting the Earth Commission (EC) of the Global Commons Alliance since its inception, contributing also to its scientific foundations (Nakicenovic et al., 2016; Rockström et al., 2024). Over the past few years, TISS scholars have been co-hosting the scientific secretariat of Working Group 1 on the Earth and Human System Modelling Inter-comparison Project, with a special focus on a bridging role between different working groups and disciplines. To this end, TISS scholars have contributed to research by the EC on the delineation of safe and just boundaries (Rockström et al., 2023; Gupta et al., (accepted). This work has included foremost setting safe climate and aerosol boundaries that account for harm to people (Lenton et al., 2023), committed impacts (Winkelmann et al., in review) and tipping dynamics (Abrams et al., 2023; GTPR 2023). Additional work has focused on quantifying a minimum access to resources for those deprived (Rammelt et al., 2022), a water boundary (Stewart-Koster et al., 2023), and biodiversity targets (Obura et al., 2022). Translating these boundaries to different actors and science-based targets is a key challenge where TISS staff have supported the development of a protocol (Bai et al., 2024; Ishii et al., 2021). The next phase will focus on pathways within a safe and just corridor (Rockström et al., 2021; van Vuuren et al., 2022).

The TISS RG has been leading the virtual interdisciplinary Tipping Points Discussion Series, a joint endeavor of the EC, WCRP's Safe Landing Lighthouse, AIMES, and Future Earth. Since September 2021, 25 webinars on Earth and human system tipping have featured ~90 experts discussing the state of knowledge on irreversibility and abrupt change.

TISS Highlights of scientific output and policy impact

- A pathbreaking paper by Brutschin et al., 2021, that introduces **a multidimensional framework to assess scenario feasibility**, has served as a foundation for a new stream of studies that now also incorporate governance and institutional indicators to assess the feasibility of required scale and speed of transformations under ambitious climate mitigation scenarios. This work also fed into the IPCC assessment of feasibility of mitigation pathways in its AR6 WGIII report and has underpinned the governance model intercomparison study within the ENGAGE project.
- A timely publication by Pachauri et al., 2021, explores how **access to clean cooking services** could improve under alternative baseline and climate mitigation scenarios, as well as a specially designed COVID-19 recovery scenario. The work highlights that the already slow progress on expanding clean cooking access might further stall and exacerbate global inequities if there were a protracted recession after the pandemic or ambitious climate mitigation action is implemented without additional support policies to expand energy access and protect the poor. It concludes that utilizing pandemic recovery and climate funds to specifically target the poorest people and regions to make clean cooking services accessible and affordable is urgently needed. The results of this research have been highlighted in policy briefs (e.g., Leveraging energy action for advancing SDGs UNHLPF 2021).
- A groundbreaking study, for which Jarmo Kikstra received an Early Career Research Award from the Integrated Assessment Modeling Consortium, focused on quantifying the additional **energy required to provide decent living standards to everyone**, including infrastructure needs (Kikstra et al., 2021). It concluded that this is less than half of the projected future energy demand under climate goals, implying that the two goals are compatible, an important insight that was also highlighted in the latest IPCC AR6 reports. The study attracted broad coverage both in media (e.g., World Economic Forum, Carbon Brief, and Grist) and policy (e.g., a policy brief for UN DESA6). Multiple projects and studies are now built on this work, including studies under JustTrans4All, ELEVATE, and EDITS
- A recent research report on **equity in emissions pathways at the EU level** provides a systematic consideration of fairness, building on international and European law principles, to suggest fair allocation approaches of mitigation effort within the EU (Pelz et al., 2023). This work informed the European Scientific Advisory Board on Climate Change and has underpinned the setting of the EU's 2040 targets.

- **Support to Working Group 1 of the Earth Commission (EC) of the Global Commons Alliance** has resulted in several high-level publications already mentioned above (Rockström et al., 2021; van Vuuren et al., 2022; Rockström et al., 2024; Bai et al., 2024) and a highly attended and impactful virtual webinar series to advance knowledge about tipping points, irreversibility, and abrupt changes in the Earth system. The series has been attended by around 4,000 participants and recordings of the events have collected several thousand views.

4.5.2. SWOT analysis of TISS

Strengths	Weaknesses
The **strengths** of the TISS research group begin with its exceptionally talented and highly skilled research staff, who bring expertise and innovative thinking to their research efforts. The small but agile group can adapt swiftly to emerging challenges and opportunities. The interdisciplinarity of the team allows for leveraging diverse methodological approaches to tackle complex issues from multiple angles. The ability to integrate traditionally qualitative research domains with quantitative scenario analysis has become a distinguishing feature of the TISS RG, providing a significant advantage. The mix of senior emeritus level scholars with mid-career and early career scholars, as well as visiting scholars, provides a broad and diverse mix of experience and expertise within the group. The group's extensive international networks facilitate global collaborations and knowledge exchange, enhancing their research impact. Furthermore, the group benefits from robust collaborations both within the ECE program and across the broader IIASA community to drive forward cutting-edge research initiatives.	The group faces some **weaknesses** that have an impact on its effectiveness and sustainability. Fluctuating and uncertain budgets create significant resource constraints and make long-term planning and staff retention challenging. A reduced inflow of internal funding to ECE and greater reliance on external funding limits the flexibility to pursue blue sky research, limiting the capacity to undertake innovative high-risk projects that could lead to methodological advancements and groundbreaking new insights. This also brings with it an additional risk of diluting the group's efforts across scattered projects, leading potentially to challenges with maintaining a cohesive research focus.
Opportunities	**Threats**
The TISS research group is well positioned to capitalize on several promising **opportunities**. The increasing realization and demand for addressing equity and justice considerations in policies and actions to transform energy systems provides fertile ground for the group to engage in and expand its research in ways that can have positive real-world impact on policy and decision-making. Furthermore, the availability of new datasets, including from satellite observations, provides opportunities for more granular analysis, enabling the group to generate more precise and actionable insights. The expertise of the group in leading stakeholder engagement processes and addressing critical political economy dimensions of transitions allows for informing the design of policy and action that has the potential to be both more feasible and acceptable. Leveraging in-house collaborations can help the TISS research group to foster interdisciplinary research that integrates diverse expertise. For instance, the formation of the new ICI research group opens new avenues for exploring how climate vulnerabilities and impacts intersect with socioeconomics and demographics and a lack of access to decent living standards. Finally, the emergence of new funding streams offers the potential to secure more stable financial support that can enable the TISS RG to pursue its long-term research goals and enhance its contributions.	The TISS research group also faces some **threats** that could hinder its work and future progress. Maintaining a delicate balance between research, capacity building, and networking activities is challenging, potentially stretching resources thin and impacting the quality of outcomes in each area. Additionally, striking a balance between retaining in-house talent and attracting new talent is crucial but difficult, as both are essential for maintaining a dynamic and innovative team. The increased effort and time required for internal administrative processes further strain the group's limited resources, diverting attention from core research activities. Compounding these issues, shrinking internal funding threatens the group's ability to support its projects and staff adequately, jeopardizing its long-term stability and success.

The complete report of the Energy, Climate and Conservation (ECE) Program is available at the following link: ECE Self-assessment report 2021-2024.

5. Program: Economic Frontiers (EF)

5.1. Overall Program Achievements 2021-2024

5.1.1. Research and internal collaboration

Program organization: Following its inception from scratch, the **EF program** has been conceived to cover four fields:[1]

- Economics of disruptive changes (**EDC**), touching on aspects of resilience,
- Economics of equal life chances (**EELC**), touching on aspects of heterogeneity/inequality and human capital,
- Economic governance of transitional change (**EGTC**), touching on aspects of governance,
- Economic development and wellbeing in a finite and interlinked world (**EFW**), touching on aspects of sustainability.

Over the first three years of the program, the EDC and EELC fields have been developed with priority although much of the thematic research relates to more than one field, generating a close integration of "working lines" across fields wherever this is appropriate from a substantive or analytic perspective (see the attribution of EF research topics to the four fields in Table 1 below).

Science-oriented objectives from the research plan: The following three objectives, as taken from the 2021-2024 research plan, relate to scientific achievements:

a. Advance the frontiers of research in the EELC and EDC fields (and develop research groups).
b. Establish a cutting-edge research agenda and initiate research on the EGTC and EFW fields.
c. Collaborate with other programs on multidisciplinary approaches within EF research and contribute economic components to modeling outside EF to leverage impact.

In the following, we describe in detail in which ways these three goals have been met. In doing so, we do not respond goal by goal, but due to their interlinkage, we provide a holistic account with some summary conclusions towards the end of the section.

Program Remit and Positioning: The EF program has been conceived to **take economics beyond the frontiers of mainstream analysis**, not the least by embedding it within the IIASA research contexts, while at the same time **leveraging the rigorous principles and methods of economics** that stretch beyond pragmatic "toolbox" applications. To address the first ambition, EF aims at taking a profound account of (i) **complexity** and **uncertainty** and ways to incorporating them into **decision making**; (ii) the **heterogeneity** and **diversity** of the population in terms of their preferences and "endowments", behaviors, and resulting outcomes; (iii) the interlinkages between transitions and policy making and the **distribution** and **inequality** of resources and outcomes across socio-economic, demographic or spatial strata; (iv) an orientation on multidimensional **wellbeing** rather than GDP; (v) the **embeddedness of the economic system** into a population, climate and eco-system, including the full set of interactions, and resulting from this the need to take a **multidisciplinary** perspective. Addressing these issues entails an advancement of **economic models beyond their state of the art**.

To address the second ambition, EF aims at harnessing the **comparative strengths of economic modelling**, namely (a) the **understanding of behaviors as outcome** of preferences, expectations, information/rationality, constraints and incentives; (b) the **unified modelling of behaviors and wellbeing** outcomes; (c) the **rigorous derivation of decision-rules** together with the underlying monetary and non-monetary **valuations**, a joint understanding of which is key for policy making; (d) a thorough and endogenous accounting for the **dynamic feedback** between **micro-decisions and macro-outcomes** within the

economic system; (e) the clearcut **distinction of optimal as opposed to suboptimal outcomes** within decentralized economies, where the latter can be attributed to wrong incentives as opposed to missing information or lack of rationality, together with an **identification of policy rules** that are apt to improve welfare.

Development of modelling frameworks and research themes: Following the above principles and its prime objectives for the initial years, EF has developed three **flagship modelling frameworks:**

1. an advanced **optimal control-model** allowing for the rigorous analysis of decision-rules and the underlying valuations under stochastic **regime-switching** disruptions, including among others eco-system destruction, climate tipping, technological breakthroughs (2-Stage Optimal Control with Stochastic Switches - **2SOCS**),
2. an advanced and **demographically realistic model of overlapping generations** of **heterogeneous** households modelled along their entire **life cycle** to trace out **diverse behavioral responses at different life stages** to environmental, technological, and socio-economic transitions, as well as the resulting outcomes over time and across socio-economic strata and generations (Model of Inequality Within and Across Generations - **MIWAG**), and
3. a dynamic model of **intertemporal decision-making of heterogeneous households** facing environmental or economic **risks** (Model of Risk Behaviors - **MORIBE**).

These frameworks, complemented by a set of other models and tools, form the basis for providing, in specific applications, **policy-oriented analysis** towards understanding:

- what behavioral changes are required to **achieve social and environmental transformations**,
- what policies and institutional reforms are needed to **bring about the required incentives** in an effective, efficient, and equitable way, and
- what is the **impact on wellbeing** across social strata, geographical scales, and time?

Notably, while the 2SOCS and MIWAG frameworks are "naturally" lodged with the EDC and EELC fields, respectively, MORIBE is lodged between the two lines. The application of modified versions of the frameworks to topics across research fields generates further integration on the methodological side.

From a **thematic perspective**, the research undertaken in EF can be grouped into five areas, as illustrated in **Error! Reference source not found.**. The table reports for each of these t hemes exemplary key research that has been completed or is ongoing, as well as how it is linked to the four fields and whether it involves cross program or external collaborations. Aspects of the work and collaborations, together with some highlights will be developed in the following.

Table 5-1 Economic Frontiers key research

Themes	EELC	EDC	EGTC	EFW	Framework	IIASA Collaboration	External Collaboration
1. **Resilience and optimal decisions under stochastic disruption**							
Development of COVID vaccine					2SOCS		Uni Padova
DICE model with climate tipping					2SOCS		Uni Padova
Conceptualizing Resilience					2SOCS		
2. **Inequality in human capital accumulation and wellbeing within and across generations**							
Redistributive Effects of Pension Reforms					MIWAG	POPJUS	TU Vienna, Austrian National Bank
Inequality in longevity expansion (RIWAG, Austrian Grant)					MIWAG		TU Vienna, Vienna Institute of Demography
3. **Preventive and adaptive behavior of actors in the presence of risk**							
Household responses to disaster (flood) risks					MORIBE	POPJUS	TU Vienna
Farming responses to economic and environmental shocks (PVARGLOBIOM; Austrian Grant)					MORIBE	BNR	
4. **Climate and energy transitions: inequality, wellbeing, policy**							
JustTrans4All (SI internal grant)						ECE, POPJUS	
JUSTCOAL (Austrian Grant)					2SOCS	(follow-up: BNR, POPJUS)	TU Vienna
MULTIFUTURES (Horizon Europe)					MIWAG		HE Consortium
Environmental policy analysis					Various		Indian Inst of Mgt. Ahmedabad, U Bologna & others
5. **Health, innovation, and population**							
COVID-19 containment					SIR/SIS models	ASA, POPJUS	TU Vienna, Carnegie Mellon, U Tilburg, Harvard School of Public Health & others
Heath systems transitions, medical progress					Various		Vienna Uni of Econ & Business, U Bologna & others
Economic burden of disease					(Harvard) Health Macro Model		Harvard School of Public Health, Uni Heidelberg, Vienna University of Econ and Business
Population change					Various	POPJUS	Various
Chapter 5 Flagship Report					FeliX systems model /YoGL indicator	POPJUS, ECE	

Notes: Dark blue = prime field(s); light blue = supplementary field(s)

1. **Resilience and optimal decisions under stochastic disruption**

EF researchers have focused on developing the **2SOCS framework**. A key strength of the model is that it allows to develop in great detail the **nexus of anticipative ex-ante choices** (e.g. in regard to risk mitigation or the build-up of adaptation capital, but also in regard to the build-up of pollution or the running down of crucial resources) and the pathways of **ex-post adaptation** to a possible shock, where the states of the system around the (random) arrival of the shock provide the mathematical nexus. This allows to map out in great detail the interdependencies between the choices over time and across regimes. The calculation of the emergent (monetary) valuations of different system states allows for practical economic and policy applications. EF researchers have initially applied the 2SOCS model to **study** the linkage between lock-down policies against **COVID-19 and R&D investments** into speeding up the stochastic arrival of a vaccine as a positive disruption towards changing the containment of the disease. A **second early application** is the employment of the model to study policies aimed at **pollution control** across an age-structured population **under the risk of climate disruption**.

In the course of a **YSSP project** led by EF, the 2SOCS modelling has been applied to the Nordhaus DICE model to allow for the study of how different types of **disruptive climate tipping events** (polar ice meltdown; carbon source-sink reversion; severe dip in economic productivity; direct destruction of capital) bear on the Social Cost of Carbon and optimal abatement policies ex-ante and ex-post as well as in the presence or absence of anticipation. The work is currently being developed towards a journal publication. Furthermore, EF employs 2SOCS to derive **model-based metrics** that can be employed for the **assessment and valuation of policies** under the shadow of disruptive events. EF researchers have thus derived a model-based **measure of resilience** that embraces the core components of resistance, recovery and robustness and keeps track in a forward-looking way of the resilience against the risk of cascading future shocks. In a second application in progress, EF researchers derive the **value of information on unknown disruptive processes**.

A version of the 2SOCS model is employed in the **JUSTCOAL** project, where the disruptive shock corresponds to changes of energy prices on the world market or exogenous political decisions (see also under 4) below). An application towards understanding how **policymakers should take into account the scope for social tipping** is in process.

2. **Inequality in human capital accumulation within and across generations**

With the purpose of rigorously accounting for **socioeconomic and demographic heterogeneity** in the behavioral responses and outcomes of socio-economic, demographic, technological, political and environmental **transition processes**, researchers at EF have developed the **MIWAG framework**. MIWAG derives **rich behavioral choices, including educational and health investments,** consumption choices, labor supply of individuals (or households) along the life cycle, based on a **realistic calibration (based on Bayesian melding)** to demographic and economic data, and allows to calculate the **distribution of** economic and non-economic **outcomes, including wellbeing**. Individual life cycles reflect detailed socio-economic heterogeneity as well as the cohort the individual belongs to. Cohorts are then aggregated to reflect the socio-economic and demographic make-up of a heterogeneous population. Based on this, **counterfactual analysis** is employed to **identify the impacts of alternative transition or policy scenarios on the population under study.**

Building on the premise that many pension systems exacerbate inequality by redistributing funds from short-lived and typically poorer individuals to long-lived and richer individuals, the MIWAG model has been applied to study the **impact on the distribution of life-cycle wealth of a range of pension reforms** that are currently debated. The model is calibrated to the Austrian economy, allows for self-selection of individuals into education groups and reveals the strong

variation across pension schemes in terms of their impact on inequality across education groups.

In an **Austrian National Bank funded research project**, EF researchers employ the MIWAG model to identify the **drivers behind the growing income gap in life expectancy** in the US for cohorts born between 1900 and 1960. They identify that differential income growth, medical progress against age-related diseases as well as non-age-related reductions in mortality explain differential longevity growth to roughly equal parts. Half of the differential growth across income groups and cohorts can be explained by social mobility, where individuals with favorable childhood traits increasingly select themselves into higher education and, thus, higher income groups, while leaving those with the most disadvantageous traits in the lowest income groups and with a much lower increase in longevity.

3. **Preventive and adaptive behavior of actors in the presence of risk**

In an effort to understand the impact of (potential) disruptions on heterogeneous populations, researchers at EF have developed the **MORIBE** framework, which allows to study the **dynamic prevention efforts and adaptation responses of heterogeneous agents** to a sequence of recurring shocks. Calibrated to socio-economic panel data from Vietnam and Thailand, the model has been specified to study the allocation (in terms of allocation of financial vis-à-vis non-financial assets, preventive effort, and locational choices) by households who differ in education and, thus, earning potential as well as risk awareness. **The analysis** reveals strong educational gradients in the incentives to protect against risks as well as in outcomes and analysis of different mitigating policies.

In the EF-led Austrian National Bank funded project **PVARGLOBIOM** , researchers from EF and IBF/BNR study how **financial market shocks on agricultural prices** drive land-use decisions and related changes in greenhouse gas emissions. EF researchers contribute to this analysis a variation of the MORIBE model that studies the **dynamic decisions on land-use and technological inputs of heterogeneous farming households** which are exposed to price shocks. Outcomes from this model will subsequently serve as input to the GLOBIOM model as executed by IBF/BNR.

4. **Climate and energy transitions: inequality, wellbeing, policy**

Various strands of EF research have been directed towards a better understanding of the socio-economic **drivers and impacts of climate and energy transitions**. As participants of the **JustTrans4All** SI project, EF researchers team up with colleagues from POPJUS and ECE to **study** how **net zero energy transitions** can be structured in a **just and inclusive** way. Jointly with POPJUS they have developed data and empirical designs to **operationalize the dimensions of decent living standards (DLS)** by way of Development and Health Survey data for a range of predominantly Global South countries (R&R with Nature Comm). In addition, they are developing **empirical designs to capture the link between DLS performance**, climate change and health.

EF researchers have acquired two project grants aimed at studying aspects of the climate transition. **JUSTCOAL** examines how the **transition out of coal** should be **structured to further the welfare of (former) coal mining regions**. For this, we consider a multi-sector regional economy and adopt the perspective of a regional decision-maker who is allocating investments (or divestments) into coal and renewable energy infrastructures and manufacturing with the aim of maximizing intertemporal regional welfare, including population health and employment opportunities. Particular attention is given to the **joint timing of the phase out and build-up of an alternative industry**, to the question by which policies a social optimum can be implemented within a decentralized economy of firms and households, and what are the **implications of potential disruptions**, such as an international energy crisis or the arrival of effective carbon capture and storage technologies. The approach also forms the basis of EF's contribution to an ongoing cross-program (BNR, POPJUS, EF) integrated modelling effort

towards understanding **global change** from a joint bio-physical and socio-economic perspective.

EF participates in the Horizon Europe **MULTIFUTURES** project that develops **new and unconventional policy pathways** for the EU to meet their **net zero** obligations in a way that harnesses wellbeing beyond mere economic performance as measured by GDP. EF researchers are leading the **modelling work package "Exploring and simulating alternative transition scenarios"**. While this includes leadership on the linkage across a variety of partner models to address technological change and life-style change as pathways towards a transition, it also involves a conceptualization and analysis of beyond-GDP indicators as performance metrics for the policy assessment, as well as an application of the MIWAG model to **study the impact of transitions on household lifestyle behavior and wellbeing** across different generations and socio-economic strata.

Finally, EF researchers have worked on a number of projects relating to environmental policy making, including a bottom-up integrated optimization model on the **energy transition in Gujarat, India**; the application of dynamic game theory to understand the **impact of emission taxes on pollution control** and R&D investments into abatement technologies; and the **role of policy making and technological progress** within the nexus of environmental pollution, life expectancy, and economic growth.

5. **Health, innovation, and population**

EF has developed a complementary research agenda on the **economics of health and health systems** as well as **development, population and technology**. This newly places IIASA in the fields of health economics and population economics, as two fields that are **inherently important for the transitional research** undertaken within IIASA. Following its inception during the ongoing **COVID-19** pandemic, EF has engaged in an ambitious research program on **containment policies within advanced Susceptible-Infected-Recovered (SIR) frameworks,** but also on various other aspects of the COVID-19 pandemic and infectious diseases in general. Aside from the work on the relationship between vaccine development and non-pharmaceutical interventions (see under 1) above), EF researchers have applied SIR type modelling to understand the **relationship between vaccine roll out and lockdown** policies, showing that these may be both policy substitutes or complements, depending on the particular regime, and that vastly different policy regimes may apply for very similar disease parameters and preferences about the preservation of lives and livelihoods. EF researchers have also published work on **lockdown and testing policies in disease networks** (accounting for possible transmission across different regions or subgroups of the population), and on the optimal choice of non-pharmaceutical interventions along **the development of a pandemic into an endemic disease**, including the scope for viral mutation, immunity loss and the build-up of bodily resilience within the host. On the empirical side, EF researchers have employed (i) econometric methods to establish **the relationship between climate conditions and viral spread**; (ii) innovative Bayesian melding techniques together with simulation analysis to understand the **impact of vaccine availability on case-fatality rates**; and (iii) the economic burden of disease analysis (see below) to understand the potential **macroeconomic costs of COVID-19 under a herd immunity** approach. Finally, EF has contributed to a prominently published survey on the **macroeconomic impact of modern infectious diseases**.

EF has enquired into the **nexus of health care systems, medical progress, and population change**. This includes two simulation studies based on multi-sector macroeconomic models that integrate demographically realistic life-cycle foundations of overlapping generations of individuals whose health and longevity depend on the provision of health care. These have been applied to (i) quantifying the **impact of the US health insurance expansion** on medical progress, life expectancy, (excessive) health care spending, longevity, and welfare across generations; and (ii) studying the **macroeconomic and welfare impact of healthcare policy responses** to medical progress and economic growth within a capacity constrained and crowded public healthcare system. Ongoing research applies advanced time

series techniques to study the **role of medical innovation for longevity and economic growth** between 1890–2010. EF researchers contribute to research that applies advanced macrosimulation techniques to Global Burden of Disease data in order to establish the **economic burden of disease**. Recent studies, published in prestigious medical/public health journals, include the calculation of the **economic burden of cancer** (including 29 specific types) as well as the **economic burden of COPD** for a set of 204 countries and territories worldwide.

EF has also enquired into the **dynamics of population change and its economic ramifications**. This includes research on how the **economic impact of an ageing population on economic growth** in the Global North can be reined in by adjustments in retirement and on whether the **trend towards declining populations** can be reined in by greater investments into the health and education of individuals. Based on calibrations for India and China, recent work has studied how **population change can be (optimally) controlled** through costly pro- or anti-natalist policies towards a stationary population structure. Recently, EF researchers have contributed to a survey on the **causes and consequences of fertility decline in high-income economies** that has been accepted as invited contribution to the prominent Annual Review of Economics. Finally, in collaboration with researchers from POPJUS and ECE, researchers from EF led the development of chapter 5 on "Global Systems Analysis for Understanding the Drivers of Sustainable Wellbeing" of IIASA's **50-years flagship report**, which included the first attempt at **integrating and evaluating the Years of Good Life (YoGL) wellbeing indicator within a global systems model**.

Integrating EF research into IIASA: EF has sought to strike a **balance between establishing its modelling frameworks** as a basis for EF's "signature" contribution to scientific and policy analysis; **engaging with external partners** from economics and other fields (see last column of Table 6.1) with the aim toward **building a network** that bridges economics and other disciplines in a systemic way; and **internal collaborations with other IIASA programs** aimed at harnessing complementary capabilities. Regarding **cross-cutting activities** EF has engaged in formal efforts, including participation in SI projects and applications, joint research grants and cross-program YSSP mentoring, and informal collaborations, including the cross-program development of papers and research projects. The following provides some examples:

- **Providing economic underpinnings for global models,** specifically during the PVARGLOBIOM project jointly with BNR, where detailed micro-modelling of the intertemporal decisions of farmers in response to price shocks helps to calibrate the more macro-oriented GLOBIOM, while the calibration of the MORIBE model will benefit from GLOBIOM regarding the specification of the macro-environment. Similar efforts are under way with BNR and POPJUS towards the integrated modelling of global change.
- **Collaboration on the study of population risk behavior** jointly with POPJUS. Benefits arise from the integration of empirical (POPJUS) and theoretical (EF) modelling capabilities.
- **Leveraging data with economic analysis:** The MIWAG framework is based on detailed population data e.g. on educational or family structures. EF researchers are collaborating with POPJUS with the aim of enhancing and applying this data to economic contexts.
- **Lead on IIASA-wide efforts:** When developing the case study on energy transition in South Africa for the IIASA-OECD task force and chapter 5 of the flagship report on global systems modelling, EF has convened IIASA researchers from all programs for the purpose of co-developing **integrated projects**.
- **Contributing an economic perspective on key concepts such as justice and wellbeing** in the context of the JustTrans4All SI (ECE/POPJUS), the Flagship Report (ECE/POPJUS), and a collaboration with ECE on the Austrian Assessment Report. Similar perspectives are added by EF's work on **tipping points and resilience**. The multi-disciplinary exchange is clarifying conceptualizations, enhancing a mutual understanding of different conceptual entry points, and facilitating the exchange between IIASA and economic audiences.

- **Leveraging capacity building:** EF researchers have co-mentored jointly with ASA and BNR colleagues YSSP scholars with the aim of enhancing cross-disciplinary expertise and integrated thinking.

Altogether, EF is harnessing IIASA's scientific and policy impact through its modelling frameworks, by opening economics-oriented scientific and policy communities (health, population, environment, and climate) to IIASA, and by facilitating for IIASA researchers the engagement with economic analysis and economic thinking. By tying together economic approaches across frameworks and topics EF leverages the strength of economic analysis beyond the more isolated and topic-focused economic approaches within other programs.

Goal achievement and Outlook: Altogether, EF has managed to develop and put into place **three key modelling frameworks as an analytical foundation** for performing analysis on a broad range of topics that touch on disruptive change & resilience and/or population heterogeneity in behaviors and outcomes (Goal (a)). These frameworks have been demonstrably **applied to several contexts** already, with further applications ongoing (in various stages of development). The **generality of the models** allows EF to **address a wide range** of topical **policy contexts**, including the study of risk responses; energy and climate transitions; environmental and climate policy making; as well as health and social policies; policymaking in respect to infectious diseases (Goal (b)). In developing its research agenda EF has been careful to **integrate its research fields both conceptually and through the researchers** working on them. This integration stretches not only across EELC and EDC as the two fields under primary development, but in a context-driven way includes also the EGTC and EFW fields. EF has thus laid the foundation towards developing them further (Goal (b)).

During a number of projects but also by way of less formal interaction, EF has **integrated its expertise with all other substantive research programs**. Areas which have been co-developed relate, in particular, to **COVID-policies; health and social policies; just (climate) transitions; and household responses to disaster and economic risks**. Further areas under development include agricultural transitions, health, climate, and more specifically the nexus through infectious diseases (Goal (c)). These collaborations also demonstrate the value and potential for **harnessing IIASA research across the board by integrating in a deep-dive the strong points of economic thinking** in terms of a rigorous foundation of dynamic behaviors, decision-rules and valuations in preferences, incentives, and the relevant economic, technological, political, demographic and social constraints.

While the **EF modelling frameworks** that have been established over the initial years **support a broad array of research themes**, including topical areas to be identified in response to the evaluation and as part of the new research plan, EF hosts **additional modelling competency**, including (i) vintage optimal control modelling to study planning problems in regard to human and animal population but also vintages of capital or technology; (ii) advanced techniques in dynamic game theory to explore strategic, political and governance aspects of transitions; (iii) structural economic methods for complementary empirical research; and (iv) financial economic and econometric expertise on climate and environmental transitions. These competencies can **support the future research agenda**.

5.1.2. Policy Impact and external networks

Impact-oriented objectives from the research plan
The following two objectives, as taken from the 2021-2024 research plan, relate to generating policy and scientific impact:

- Provide a platform for discussing (economic) policy and developing research toward social and environmental transformation. This forum brings together economically relevant aspects of research from all IIASA programs and will be open to relevant external (e.g., NMO) stakeholders.

- Introduce systems thinking and EF insights into economic policy debates.

In the following we describe in detail in which ways these two goals have been met. Again, we provide a holistic account with some summary conclusions towards the end of the Section.

Working towards policy impact
The focus of EF's activity during the early years has been on the development of its key modelling frameworks (as discussed in the previous section) with the aim of building a scientifically solid and trusted basis for policy analysis, assessment and advice. Thus, to some extent the application of these frameworks towards generating policy impact is forward looking with the first steps having been taken through the JUSTCOAL and MULTIFUTURES research projects, which already take the frameworks to a (more) applied stage. Aside from these projects, EF researchers have engaged in a number of activities that have already left a policy impact or have been oriented towards establishing EF's presence in the policy arena.

Towards **building a policy and scientific forum for their work on disruptive changes**, EF researchers have picked up a **keynote invitation** to present and discuss their work on resilience at the 2023 "istat Risikokonferenz" (**Risk Conference**), a high level gathering in Germany of **risk managers of prominent companies** from the manufacturing and energy sectors, including inter alia Porsche (Germany), Volkswagen (Germany), OMV (Austria), Vattenfall AB (Sweden), and SLB (former Schlumberger Technologies, US, European Division). The work on resilience has also been presented to and positively received by the **PEER Network** in 2024. Moreover, EF researchers have been invited and contributed to a panel on **"Building Back Better: After the 'Shock' and Beyond"**, **Berlin Demography Days 2024**.

Drawing on the program's work on equal life chances, EF researchers have carried out work on the **generational impacts of COVID 19** that was **supported by the UNFPA** and featured prominently in **UNFPA and UNDESA seminars** and workshops. This work is building on the **National Transfer Accounts** (NTAs), a global initiative aimed at establishing a set of intergenerational accounts worldwide, to which **EF researchers are contributing in a leading capacity for Austria and Europe**. As part of this network, they have contributed to a conference celebrating the **use of NTAs in China** for supporting policy responses to population ageing, **the 14th Global Meeting on Building Sustainable Generational Economies** in Paris, and to a **conference on sustainable development and demographic changes in Uzbekistan**, in which EF researchers explained how to use NTAs for assessing the demographic dividend, or the potential economic boosts coming from a favorable demographic structure. Recent work on the distributional impact of pension reform has been presented at the Austrian policy forum "**Denkräume St. Lambrecht**".

Tying in with their work on climate and energy transitions, members of EF have joined as lead authors, the chapter 5 team on **"demand-side transitions" of the Second Austrian Assessment Report** (AAR2, 2022-2024). They have also contributed to the **chapter 6 on "Energy Systems"** in the **IPCC's sixth assessment report (AR6) in Working Group III** (Mitigation). EF also acts as an IIASA representative on the **European Energy Research Alliance (EERA) – Bioenergy**, engaging inter alia in the preparation of a "Bioenergy Position Paper" that identifies research gaps and approaches. They are also contributing to EERA's joint program on "Clean energy transition for sustainable society (e3s)" through a **White Paper on energy demand reduction**. In 2021, EF researchers have teamed up with researchers from POPJUS to produce a **policy brief on the linkages between SDG7 (Accessing clean energy) and SDG 10 (Reducing inequality)** for a high-level report by **UNDESA's SDG7 Technical Advisory Group** on the use of energy access to leverage SDG attainment. EF researchers have also contributed to a report on **"Synchronizing energy transitions toward possible Net Zero for India: Affordable and clean energy for all"** commissioned by the Office of the Principle Scientific Advisor (PSA) to the Government of India and Nuclear Power Corporation of India Limited (NPCIL). Finally, EF researchers have contributed to a **VoxEU policy brief** on a sustainable digital transformation.

Concerning work on health and population, EF has contributed a **keynote presentation to the 4th Symposium on Population Medicine & Public Health**, organized by the Chinese Academy of Medical Sciences & the Peking Union Medical College. The topic was on **optimal health care spending** and informed **Chinese policymakers and scientists** about the fact that while health care systems may be spending inefficiently at a micro-level, health care spending at the macro level is likely to be too low from a welfare perspective. EF's work on **COVID19 containment** has been communicated through **Vox EU policy briefs** (**Brief 1**, **Brief 2**).

Since 2021 the EF program has taken the **IIASA lead on the OECD-IIASA Strategic Task Force on Systems Thinking, Anticipation and Resilience**, coordinating the engagement with OECD on the matter. Specifically, EF researchers have teamed up with colleagues from other programs and OECD units to draw up a large-scale grant proposal for EU funding on the development of integrated policy pathways towards a just and inclusive net-zero transition in South Africa in cooperation with South African researchers. Despite the initial interest on the part of the EU DG Climate, unfortunately funding was not forthcoming. Following an invitation to provide **feedback on the OECD multidimensional fragility framework**, EF has hosted a mini workshop in 2021 in which participants from IIASA and OECD discussed aspects of the framework and notions of fragility.

Finally, EF presented their work on the inclusion of wellbeing into global systems modelling, as part of the **Flagship Report**, at a global **launch event** on the occasion of the 78th UN Assembly and mid-term review of Sustainable Development Goals, as well as during a EU Commission library talk.

Network building
Besides their membership in the policy-oriented EEARE and PEER networks, as well as the IIASA-OECD Strategic Task Force, EF researchers are strongly engaged in **formal and informal scientific networks**. Per cross-affiliations of various program scientists, EF is strongly tied in with the Wittgenstein Centre and the Austrian Academy of Science's Vienna Institute of Demography. Cross-affiliations also exist with the Technical University of Vienna, the Okinawa Institute of Science and Technology, the Indian Institute of Management Ahmedabad, and the New School in New York.

Several EF researchers are **co-opted members of the Field Committees on "Population Economics" and "Health Economics" of the German Economic Society** as well as members and officers **of the Austrian Economic Association.** Close collaborations also exist with various **commissions of the Austrian Academy of Sciences and Statistics Austria.** On a less formal basis, EF researchers are linked into strong **authorship networks** on Optimal Control and Dynamic Game Theory (e.g. Jon Caulkins, Carnegie Mellon; Georges Zaccour, Gerad and HEC Montreal; Fouad el Ouardighi, ESSEC Business School; Peter Kort, Tilburg University; Luca Lambertini, Bologna University); population, health and development economics (Hippolyte d'Albis, Paris School of Economics; Uwe Sunde, Ludwig-Maximilians-Universität Munich; Holger Strulik, Uni Göttingen; Ron Lee, U Berkeley; David Bloom, Harvard School of Public Health) and environmental and climate economics (Pauli Lappi, U Helsinki; Gernot Wagner, Columbia) amongst others.

To embed their work in the field of EDC in the scientific community and to provide a new forum for researchers in this field, EF has initiated a **network on "Modelling resilience and disruptive changes"**, which is organized around two **workshops**, an **inaugurating one in 2022** and one forthcoming in autumn 2024 , and a series of **biannual seminars**. Speakers so far have included Anne-Sophie Crepin (Beijer Institute), Aart de Zeeuw (Uni Tilburg), and Eli Fenichel (Yale). Further members of the network include Frederik van der Ploeg (Oxford), Amos Zemel (Ben-Gurion University), and Florian Wagener (U Amsterdam) among others. Related to this network is EF's co-organization and hosting of the **8th Viennese Workshop** on "Heterogeneous Dynamic Models of Economic and Population Systems" in 2023.

Finally, EF has initiated the **Econ4Um Seminar Series**, which aims at bringing together IIASA and external colleagues with an **interest in economics or systems analysis of economic issues** and has so far featured 15 sessions based on presentations of both internal and external speakers. Prominent visiting speakers include Georges Zaccour (Gerad and HEC Montreal) and Fouad el Ouardighi (ESSEC Business School).

Capacity building and community services
Over the past three years, EF has hosted **seven YSSP scholars** from a range of countries (AT, CHN, Ghana, IND, IT) who have successfully completed work on inter alia, the impact of mining activities on regional economic growth and forest destruction in Brazil (joint supervision with BNR; report to revise & resubmit with Nature Communications); the inclusion of tipping points into the DICE model; unequal access to pharmaceutical abortion in Ghana; allocation of vaccines in the presence of supply rationing in India; and the scope for international climate agreements that couple emissions reductions with preferential technology access (joint with ASA; **winner of the 2023 Mikhalevich award**).

EF researchers have co-supervised two **PhD students**, tying in their work with the program's agenda on disruptive change and risk responses. In addition, the program has hosted one intern, working on the impact of developing aid on decent living standards and preparing this for her Master thesis.

EF researchers are active in providing regular **university courses in economics and operations research**. In addition, EF researchers have given an **invited lecture at Erasmus University Rotterdam on the economics of COVID-19** and its containment. Moreover, EF researchers have taught a session for the DAAD – University of Potsdam Alumni Seminar 'Risk-Management – Governing Uncertainty in a Complex World'.

EF researchers have been active in the organization of a number of conferences, most notably the **Wittgenstein Conferences 2022** (on depopulation) and **2023** (on heterogeneity of populations).

Finally, as part of EF's efforts of **establishing an open modelling environment** in the mid to long-term, the **2SOCS model framework** and the underlying **vintage optimal control modelling** have been made available as **toolboxes on GitHub**. Furthermore, the code for the **MORIBE model** is also available via GitHub. The MIWAG model will be made available after further work and verification of the code.

Goal achievement and Outlook of EF program

Over the past three years, the EF program has in many ways laid the foundation for generating policy impact. While the primary focus was to some extent on the development of the key modelling frameworks that form the scientific basis for policy analysis and advice, significant effort was expended on **introducing EF and its research to the respective scientific and policy communities**. This has been achieved by a mix of activities, including the **engagement with policy-oriented networks** (EERA, PEER, NTA) as, indeed, with **OECD**; the presentation of EF at scientific and policy fora, and participation in **community activities** such as IPCC VI and the Austrian Assessment Report. These efforts have been accompanied by **active engagement in capacity building**, notably YSSP, and the implementation of first modelling structures in an open modelling way (Goal (b)).

EF has also successfully engaged in creating a **research network on the "Modelling of resilience and disruptive changes"**, drawing the **active interest of top researchers** in the field. While EF researchers are already well connected within networks on population (e.g. the National Transfer Account network), building a similar network is envisaged in respect to the modelling of population heterogeneity. In addition, EF has initiated and is successfully running the **Econ4Um Seminar Series, functioning as an IIASA-wide forum for exchange on economics topics**. Given its firm establishment, the next step is its active promotion as a

forum of exchange between IIASA and external researchers, policymakers and other stakeholders on economic policy issues in the context of socio-environmental transformations (Goal (b)).

Based on these foundations EF has **stepped up its efforts in establishing a foothold in policy applications** both through grant applications (with notably the European Horizon Grants having a strongly applied nature) and engagement with a number of NMOs on a variety of themes (e.g. natural capital accounting and food transitions).

5.1.3. Program budget and staff

The start-up nature of the EF program is strongly reflected in the progression of its budget and staff FTEs. Both personnel and core budget spending were closely linked to hiring staff that was key for the development of the core frameworks of the program. Thus, availability of such (specialist) staff only from the mid-term onwards and ongoing COVID-restrictions on activities explain the significant underspending in 2021. Both FTEs and spending were then gradually increased in line with the available internal and external project funding.[2] In particular the successful acquisition of external funding in 2023 has allowed for a significant expansion of staffing. With further grant applications on the way, EF expects further expansion as well as a significant increase in the external funding share.

Table 5-2. Economic Frontiers Budget 2021-2024

	2021	**2022**	**2023**	**2024**
Total budget	**521.670**	**413.842**	**527.973**	**530.245**
Income from External Projects	-	-	-	105.861
Income from Internal Projects	-	21.748	36.225	15.504
Core allocation	521.670	392.094	491.748	408.880
Expenses	**299.280**	**381.994**	**478.602**	**526,000**
Total FTEs	**3,38**	**5,18**	**6,97**	**7,87**
FTEs scientific	2,38	4,18	5,97	6,87
FTEs non-scientific	1,00	1,00	1,00	1,00

In line with the build-up of the group of core researchers and its research agenda, EF has also expanded the number of guest researchers to tie in additional expertise and formalize collaborations on methods and topics that are key for EF. Overall, EF researchers come from a range of countries, including Austria, China, Finland, Germany, Ghana, India, Italy, South Korea, Morrocco, Russia, Spain, Vietnam, and USA. EF also strives to arrive at an equitable gender balance, which in 2024 stands at 39%.

Table 5-3. List of staff at Economic Frontiers Program

	2021	2022	2023	2024
Total FTEs	**3.38**	**5.18**	**6.97**	**7.87**
R1	1	3	4	3
R2	2	5	10	12
R3	0	0	1	1
R4	1	1	1	1
O-5	1	1	1	1
Total Staff	5	10	17	18

List of externally funded projects (approved from 2021 to March 2024)

Project: PVARGLOBIOM
Title: Long-term spillover impacts of financial markets on the environment
Period: 01-NOV-22 till 31-OCT-26
EF Program Share: EUR 73,085.75
Abstract: The proposed project aims to capture the medium to long-term spillover effects of financial markets and related stakeholders such as regulatory institutions on climate-relevant emissions from land-use and changes to its pattern. EF is collaborating with IBF and developing an intertemporal model of the land-use and technology choices of (partially) forward-looking and heterogeneous farming households in the presence of financial market risks and possible credit constraints. The detailed model of intertemporal behaviors will be calibrated based on VAR analysis of price movements. Its output on risk responses in terms of land-use and technology will inform the calibration of IBF's GLOBIOM model.

Project: JUSTCOAL
Title: Modelling the regional welfare impacts of coal transitions in the context of net-zero climate goals
Period: 01-NOV-23 till 31-OCT-26
Total project funding: EUR 324,574.87
IIASA Share: EUR 249,588.21
Abstract: Coal, the most carbon-intensive fossil fuel, is also central to many regional economies that rely on its mining, transportation, energy production or exports. In this context, just coal transition entails finding ways for coal phase-out without impacting the regional economies. This would ensure that policies aimed at global emissions reduction and environmental protection do not cause undue harm to local communities that have a major dependence on coal-based industries for their subsistence and employment. With a focus on just transitions, we propose to study and model the welfare impacts of energy transitions for regional, coal-dependent economies. Our approach, grounded in optimal control theory, includes modelling on how coal-to-renewable transitions should be structured at a regional level when taking explicit account of the labor market, health and welfare implications for the local population. Further, we develop scenarios for just transitions based on gradual versus disruptive changes in regulations and technologies to inform regional policies with respect to economies that are under different stages of development and coal transitions.

Project: MULTIFUTURES
Title: A multi-methods approach towards developing novel policy options towards developing multi-dimensional transition futures
Period: 01-JAN-24 till 30-JUN-27
IIASA Share: EUR 395,389.95
Abstract: MultiFutures systematically broadens the scope for policy action towards sustainable societies by assessing and developing transition scenarios based on alternative economic paradigms. This involves extending established transition scenarios (e.g. the EC's 'Long term

strategic vision' scenarios or the IEA's net zero scenarios) to include alternative economic paradigms that are based on a wide spectrum of sound economic and social theories and have demonstrated potential to address global challenges. These paradigms introduce new policy options and instruments, which we aim to critically assess regarding their relevance, effectiveness, and potential trade-offs. EF leads a work package on the development of an integrated modelling framework and will contribute the RIWAG model to study the impact of policy pathways on lifestyle (behaviors) and economic and non-economic outcomes across the socio-economic and age strata of a population.

5.2. SWOT analysis of Economic Frontiers Program

Strengths	Weaknesses
• EF's three modeling framework are based on highly advanced methodology, are general and, for this reason, adjustable to many current and future topics relevant for IIASA. • EF is one of few groups capable of integrating the strength of economic analysis (endogenous modeling of behaviors, optimal decision-rules, rigorous modeling of institutions and policies) with heterogeneity, uncertainty and system complexity. • Reliance on own rather than adopted models and frameworks. • Strong integration of research methods and fields within EF. • Researchers embedded in long-standing and high-profile external research collaborations; EF has successfully established scientific visibility.	• Possible overdiversification in terms of themes, but notably this is partly reflecting the fact that EF actively develops unified frameworks to different areas and partly reflecting EF's role as a provider of "deep-dive" economic analysis across diverse topics. • With the focus on framework building so far, the applications' angle needs to be rolled out. • NMO ties in terms of actual model applications should be strengthened, and more follow-up on initial contacts is needed. • IIASA internal collaborations have been successfully initiated but should be formalized and strengthened (funding!). • External funding is still low (but growing).
Opportunities	Threats
• Connecting IIASA (back) into economic research and debate; and vice versa strengthening economic thinking and concerns within systems science community. • Capacity building in the above regard. • Methods, nexus of topics and its embeddedness within IIASA create significant differentiation from mainstream economic units (methods), specialized economic units (integration of topics) and multidisciplinary institutions that cover economics by off-the-hook methods. • With established frameworks on the ground, EF researchers have additional modelling tools (vintage optimal control, dynamic game theory, structural methods, financial economics) to their avail to tackle emergent themes.	• Model complexity may inhibit applicability (conversion into simpler tools needed) and makes funding acquisition more difficult. • Both the development of economic modeling and even more the process to publications are tedious and lengthy. • Risk of falling between all chairs in positioning (too economically nitty-gritty for general or systems audience; too systems oriented for economic audience). • Not yet too big to fail. • Economics is an extremely competitive field for publications and grant acquisition.

The complete report of the Economic Frontiers Program is available at the following link: EF Self-assessment report 2021-2024.

6. Program: Population and Just Societies (POPJUS)

The Population and Just Societies (POPJUS) Program was established to bridge applied systems analysis with equity and justice considerations, while also leveraging IIASA's expertise in population and human capital modeling, measuring human wellbeing, and understanding diverse values and behaviors through participatory research. The research in the POPJUS program is people-centered with the goal to support transformative governance and inform evidence-based policy options for creating more just and equitable societies. The program underwent several leadership changes during this period, with Raya Muttarak serving as Program Director in 2020-2021, followed by Samir KC as interim director in 2021-2022, before Anne Goujon took on the leadership in 2022. Similarly, at the research group levels, except for the EQU research group, most groups experienced multiple changes in leadership through the 2021-2024 period. Nevertheless, POPJUS has thrived during this time, accomplishing most of the set goals and developing a solid foundation for relevant future research to foster sustainable societies.

6.1. Overall Program Achievements 2021-2024

6.1.1. Research and internal collaboration

The program has been particularly successful at integrating and cross-fertilizing among the different research groups. Additionally, it has excelled in collaborating with other researchers within the institute, for instance within Strategic Initiatives or institute-wide workshops, facilitating a profitable exchange that serves the purpose of systems analysis. This collaborative environment not only enhances the quality and scope of research but also promotes innovative solutions to complex problems by leveraging diverse expertise and perspectives.

a. **Advance the empirical inclusion of population, socioeconomic, and spatial heterogeneity in analyses and modeling, as to enable better integration of the social dimension in systems analysis models.**

Understanding heterogeneity is crucial for formulating effective policies and interventions. By examining the multiple layers of heterogeneity, we can gain a comprehensive understanding of the complex interplay between different factors and their cumulative impact on individuals and communities. Heterogeneity in people's behavior, encompasses not only demographic aspects such as fertility, mortality, and migration but also extends beyond demographics to include factors like voting behavior, exposure to and vulnerability from climate change, and conversely, the impact of people on the climate. There are many layers of heterogeneity to be explored across various dimensions, including country, age, sex, education, place of residence (urban/rural), geographical location, income, labor force participation, health status, and more.

The original idea was to include the place of residence in a new round of the Wittgenstein Centre[1] global population projections, following the Shared Socioeconomic Pathways (SSPs), together with the other variables such as age, sex, and education. However, in 2021, the SSP community required an update, whose timeline did not allow for the inclusion of the urban/rural dimension in the projections. However, the 2023 update of the projections (published in 2024) includes the dimension of education which has been shown to correlate with many outcomes. As an example, during the 2021-2024 period, several papers have shown the variability of human-capital mobility by education? at regional level in the context of the economic crisis (Gonzalez-Leonardo 2023), the importance of maternal education for child survival and the differences existing by place of residence (Moradhvaj and KC 2023). This is important because education is spatially distributed as shown in the example of China (Wu and KC 2022). Education was also studied in the context of how it translates into skills and productivity (Lutz et al. 2021; Marois et al. 2022). Our findings suggest on the one hand that education will be key in reducing the impact of ageing by increasing the productivity of the labor

force. On the other hand, we also show that if we adjust education with the skills acquired, we noticed a widening global skill gap between low – and high performing countries.

Spatial heterogeneity, also extending beyond the traditional urban and rural dichotomy, has been a focal point within the program across all research groups, emphasizing the importance of addressing challenges at the local level. This comprehensive approach recognizes the unique characteristics and needs of different localities, ensuring that solutions are tailored to specific contexts. The program's efforts to reinforce spatial heterogeneity involve examining various factors such as geographical (e.g., in the case of migration), socio-economic conditions and vulnerabilities (e.g., WP3 in the SPARCCLE project in collaboration with the ECE Program, or the LivWell and DISCC-AT projects), interaction between natural resources use and human populations (e.g., the BALANCE project), political (e.g., the Climate Modernity project) and environmental impacts on populations (e.g., Li et al. 2022 or Yokomatsu et al. 2024). By doing so, it provides a nuanced understanding of how these elements interact and influence outcomes at the local level. This approach not only enhances the relevance and effectiveness of research findings but also supports the development of more targeted and sustainable interventions.

b. **Strengthen research capacity to apply innovative methods and new data sources to identify sustainable development challenges and explore people-centric systems solutions for sustainable, resilient, equitable, and just societies through empirical and scenario-based analyses.**

The program has embraced cutting-edge methodologies to address sustainable development challenges. This includes the use of advanced statistical techniques such as:

- Bayesian modeling for estimating fertility by age and education, for understanding displacement or environmental concerns;
- Machine learning applied to understand climate migration, monitor and project hunger, or predict the health status of populations;
- Microsimulations to project future populations according to several scenarios to assess labor force participation – in particular depending on different assumptions for migration – and its productivity, health and ageing of various populations;
- Multidimensional population projections including education as a projection parameter (e.g., global updates of the SSPs).
- Dynamic macroeconomic modeling of climate-related disaster impacts, considering multidimensional household heterogeneity, for analyzing changes in growth and inequality in low-income countries.

POPJUS also utilizes games and policy simulation scenarios to tackle complex socio-environmental challenges and develop effective strategies. For instance, we explored collaborative governance models to enhance ecosystem resilience and community engagement in the context of the implementation of Nature-based Solutions (NbS) for river basin management (PHUSICOS). In another project (ABM2POLICY) in collaboration with the ASA program, a gamified ABM-based policy simulation was developed to understand the multi-party policy process in the context of the arrival of a large wave of migrants to Austria due to climate extremes in the Middle East and North African region. The RESPECT role-play simulation aims at closing prevailing science–policy–implementation gaps in Climate Risk Management, which are often a result from insufficiently clear roles and responsibilities, diverging stakeholder interests, priorities and risk perceptions, and inexistent or incipient cooperation mechanisms. Additionally, in the RECREATE project, policy exercises and elicited shared stakeholder values were used to provide bounds of acceptability of innovative urban mobility solutions to meet ambitious climate targets, in the case of Vienna and Shanghai. These simulations provide valuable insights by integrating diverse stakeholder perspectives, ultimately guiding policymakers toward sustainable and equitable solutions. By leveraging these innovative methods, researchers can uncover

patterns and trends that traditional approaches might miss, leading to more accurate and insightful analyses.

One main innovative methodological contribution of POPJUS has been in estimating and projecting migration (QuantMig, FUME, Global migration flows), involving sophisticated methodologies that integrate both qualitative (Delphi surveys among policymakers and expert surveys) and quantitative analyses.

The program has expanded its research toolkit by incorporating new and diverse data sources. These include non-traditional datasets that provide real-time and granular insights into population dynamics and social behaviors, for instance by exploring Reddit as a useful data source to analyze public discourse on climate change. Scenario-based analyses allow the program to explore various future possibilities and their implications. Combined high-resolution climatological data with regionally aggregated, harmonized Eurobarometer data and European Parliamentary electoral data allowed us to show a significant effect of climate change experiences on environmental concern and voting for Green parties.

c. **Engage in applications of methodological tools and concepts in the social sciences using evidence from micro and macro data and scenario-based approaches to inform policy options.**

POPJUS has strived to develop new tools and concepts and this in three main directions:

- New indicators of well-being to support policymakers and researchers in identifying key areas for improvement and crafting targeted interventions, evaluating progress towards equitable and sustainable societies: The Empowered Life Years project exemplifies the creation of new well-being indicators. This project developed the "Years of Good Life" (YoGL) indicator, a comprehensive measure that can be applied across various societies, providing the foundation for evaluating transformative policies and progress across countries. The YoGL indicator combines universal components of well-being, including health, literacy, happiness and being out of poverty. To ensure its relevance and applicability, the indicator was tested through focus groups in diverse contexts such as Nepal, South Africa, and Costa Rica, providing valuable insights into its versatility and robustness.
- Well-being and Loss and Damage from Climate Change: POPJUS researchers have developed a human well-being based proposal for assessing risk of loss and damage from climate change and suggested to put multidimensional inequalities in human wellbeing at the centre of transitions.
- Better measurement of ageing by applying new 'prospective' measures of aging away from chronological age, using the Remaining Life Expectancy metric, which is relevant for various fields, including insurance, retirement planning, and public health policy. It can help policymakers make informed decisions about health, financial planning, and resource allocation.
- Expert views on future demographic trends and their drivers: The field of demography is advancing to a point where the predominant theory, the demographic transition, may not adequately explain evolving trends, especially in the global north where fertility rates are concerned. In seeking answers, POPJUS, in collaboration with the European Commission Joint Research Centre and the United Population Division, has conducted an expert demographic survey whose results are currently under discussion in various academic circles and with policymakers. The findings of the survey and ensuing dialogues will be key to inform the next round of global population projections.
- Operationalizing path dependency for effective climate adaptation: Adaptation pathway approaches (APAs) have become an increasingly popular means of facilitating local and regional anticipatory planning under the influence of climate change. Many studies in this field of research identify path dependencies as a key barrier to adaptation efforts. However, their respective definitions of path dependency are often vague and impede a

comprehensive integration of this concept into APAs. We propose and test a conceptual framework for or analyzing path dependency in empirical studies using APAs or in decision making processes for compound climate risk management.

d. **Assume leadership in establishing a framework that enables IIASA researchers to take into account aspects of equity and justice in their projects focusing on grand societal challenges and consider pluralities and heterogeneities both conceptually and empirically (e.g., population, vulnerability, risk perception, values, and norms).**

POPJUS with the Equity and Justice Research Group has emerged as a pioneering force in shaping a framework that empowers researchers to integrate equity and justice considerations into their projects aimed at addressing grand societal challenges across different governance levels. Through their leadership, the group has facilitated a paradigm shift within IIASA, encouraging scholars to embrace a holistic approach that acknowledges and respects pluralities and heterogeneities. This framework extends beyond mere conceptual discourse to practical application, for instance in disaster risk management and more specifically in the case of wildfire risk management, ensuring that aspects such as population dynamics, vulnerabilities, risk perceptions, values, and norms are comprehensively examined both in theory and in empirical studies. By fostering a culture of inclusivity and mindful inquiry, the Equity and Justice Research Group has not only enriched the quality of research at IIASA but has also contributed significantly to fostering sustainable and equitable solutions to the world's most pressing issues.

e. **Advance applied research toward transforming social, economic, and governance systems such that they contribute to equitable and sustainable societies.**

POPJUS has contributed toward this goal by developing and implementing interdisciplinary frameworks that prioritize equity and sustainability. By conducting comprehensive studies that integrate demographic analysis with social and economic variables, POPJUS has been able to identify and address systemic inequities. This research encompasses a wide range of factors, including population dynamics (and potential futures), socioeconomic disparities, governance structures, and environmental sustainability. POPJUS's initiatives have led to the formulation of policy recommendations and strategies that promote social justice and sustainability, as exemplified by the policy briefs published between 2021-2024 that look for instance in tackling governance barriers to nature-based solutions and developing innovative policy and finance schemes to promote them. Supporting governance transformations as a scientific institution requires close collaboration with stakeholders from all parts of society. In the context of our NbS governance and finance focus, we implemented four international policy-business fora, four webinars attended by hundreds of people and a Finance Innovation Festival with ~100 experts.

Reaching limits to climate adaptation will also require fundamental changes social, economic and governance systems. Our research has the shown that also Global North countries will be subject to constraints and (soft) limits to adaptation with progressing climate change and some population groups will be confronted with livelihood transformations. Increasing climate-related risks will therefore require a transformation of current governance structures towards an adaptive and integrated climate risk management approach to tackle losses and damages from climate change. Similarly in the study of international migration, the research has shown that there is a need to shift the debate on migration towards the mainstreaming of migration uncertainty in the political and policy discourse, and away from either the "illusion of control" of migration or overreacting to specific events, often fueled by availability of higher-frequency data on some migration processes and not on others.

f. **Scale up cross-cutting research activities enabling the empirical integration of demographic and social components in IIASA models, both as drivers of sustainable human wellbeing and as a system affected by changes in natural and economic systems.**

POPJUS has effectively scaled up cross-cutting research activities at IIASA by integrating demographic and social components into its comprehensive models, thereby enhancing the empirical analysis of sustainable human wellbeing. This integration is achieved through several concrete initiatives and projects:

- The Shared Socioeconomic Pathways (SSPs): POPJUS has contributed to the development and refinement of SSPs, which are integrated scenarios used for instance by the IPCC to model the potential impacts of various socioeconomic pathways on climate change and sustainability. By incorporating detailed demographic data, such as population age and sex structures, education, fertility, mortality and migration patterns, POPJUS has enriched these scenarios to better reflect the interplay between demographic factors and environmental and economic systems.

- Studying and integrating differential Vulnerability in IIASA's models: This has increased importantly over the research period, and in several directions, for instance developing resilient climate-related health systems, together with the ASA program within the REACH project; mapping and forecasting the EU population vulnerabilities in the context of the SPARCCLE project together with three other research programs: ECE, BNR, and ASA;

- POPJUS participates in several Strategic Initiatives to push the boundaries of systemic analyses, and particularly aimed at integrating justice and equity issues in system analysis, such as fairSTREAM, JustTrans4ALL, and TRUST.

- The program has initiated discussions on several cross-cutting topics in the institute's research agenda, including Justice, migration, and health (forthcoming in 2024), to gain momentum on addressing these challenges.

Through these examples, POPJUS demonstrates a robust commitment to incorporating demographic and social dimensions into IIASA's modeling efforts, thereby providing a more comprehensive and empirically grounded understanding of the pathways to sustainable human wellbeing.

6.1.2. Policy Impact and external networks

Several initiatives collectively highlight the program's success in enhancing policy impact through participatory processes, interdisciplinary research, and effective stakeholder engagement, contributing to the development of sustainable and evidence-based policies. Here are a few highlights:

POPJUS researchers have identified that **participatory and co-design approaches with policy stakeholders** are key to understand collectively the policy process and empower people. It has been implemented in several settings. For instance, in Styria, one of the 9 Austrian provinces, a transdisciplinary group of researchers, practitioners, and policy- and decision makers engaged in 2022 in a participatory process called "climate modernity" with the aim to co-create courageous and positive visions for a low-carbon and climate resilient future. Our scientific accompanying study assessing the process's effect on participants' self- and response efficacy regarding possible mitigation measures, shows that participatory processes could raise trust in the democratic process and in the effectiveness of making a green voting decision. Similarly, in the RECREATE Policy Simulation project, Viennese stakeholders in mobility and transport were involved, using a virtual conference setting, to discuss emissions reduction and public space management. The outcomes, which emphasized the importance of compromise and understanding diverse viewpoints, influenced real policy processes. POPJUS are also influencing policy upstream by contributing to the project makingAchange, in which school and university students in Austria can participate in a peer-to-peer training, gaining technical knowledge and developing methodological skills to become a contact person in daily climate change debates and discussions.

Scenario-making and narratives for projections to inform policy: There is a plethora of research projects in POPJUS that implement projections as a tool to understand the consequences of past, present, and future political decisions. For instance, in the BALANCE project where POPJUS researchers are developing a strategic tool for decision making in Norway that enables policy makers to evaluate alternative strategies for a circular bioeconomy in terms of the goals of value creation and employment, greenhouse gas emission reduction and resource efficiency. Similarly, the SSPs that are scenarios used in climate research to project and analyze potential futures based on varying socio-economic developments and their impacts on climate change, are central to understanding how different societal choices and policy directions can influence climate outcomes. They are part of the framework used by the Intergovernmental Panel on Climate Change (IPCC), and therefore very influential.

Conveying migration uncertainty to policy makers: Migration is at the core of policy debates, particularly in the European Union but not only. The White Paper on Migration Uncertainty that was developed in the framework of the QuantMig project provided insights into enhancing foresight and preparedness in migration policy. Similarly, we provided a Science-Policy Interface in Climate Migration with initiatives such as a TEDx Talk on climate change and population dynamics and a study on bridging the science-policy gap in climate migration highlighted the importance of translating scientific research into actionable policy.

The transformative potential of Nature-based Solutions: A series of projects and publications focused on the transformative potential of NbS, addressing policy barriers, and proposing governance innovations across multiple scales. Key outputs included comparative case studies, policy briefs, and deliverables on opportunities, barriers, and governance innovations for NbS, providing comprehensive guidelines for managing climate risks, reinforcing the importance of NbS in policy-making.

Health, health systems and policy reforms: Health policy reforms are essential for building resilient citizens and equitable, and efficient health systems. This vast policy-relevant research is being tackled in the context of several POPJUS projects such as CHIAS, which is looking at the implications of different policies/initiatives that exist in different EU countries/cities that (directly or indirectly) promote healthy cognitive aging. In the context of climate change, we are also studying ways to support health systems that are faced with environmental stresses such as floods and heat extremes. The REACH project implemented in Zambia and Brazil is in the process of developing models to support local-level decision making regarding climate adaptation. The research involves iterative and ongoing engagement with policy makers to ensure their views and needs are addressed.

During the 2021-2024, the POPJUS program has entered several large networks that have increased our policy impact.

With the **European Commission Joint Research Centre** (JRC), with is the research arm of the European Commission, we have been engaged in several projects with high policy relevance:

- Quantifying the exposed and vulnerable populations to climate change in Africa based on climate, demographic and socio-economic scenarios and analyses past trends, which contributes to the ongoing integration of EU policies on climate change, adaptation and migration. Within the SPARCCLE project, we are also collaborating with the JRC on assessing the socio-economic vulnerabilities of Europeans to climate change, leading (forthcoming) to a story in the Atlas of Demography which has been initiated by the European Commission Vice-President for Democracy and Demography.
- Analyzing the impact of the Russian invasion on the longer-term future of Ukraine's population size and structure, by focusing on varying assumptions on the extent of the displacement triggered by the war, the level of return migration, and possible future migration patterns of temporary, circular and permanent movements. This work

contributes to forward-looking policymaking supporting the long-term economic and social recovery of Ukraine by anticipating possible consequences of migratory movements on longer-term population trends in Ukraine.

- Thinking about future demographic trends beyond the demographic transition and implications for population policies, also in collaboration with the United Nations Population Division, the leading producer of global population projections.

More recently (in 2024), we entered in a partnership with the **Organization for Security and Cooperation in Europe** (OSCE) in the context of migration and climate change which will lead to the design of policy options with experts, stakeholders to strengthen the resilience of population in South-eastern Europe.

Several POPJUS researchers are members of World Health Organization reference groups on Global health statistics and on the Metric and Life Course, providing advice on population-health related statistics and indicators of relevance to WHO.

POPJUS is participating in the Austrian Panel on Climate Change (APCC) through various activities. Most recently, POPJUS researchers act as Coordinating Lead Authors and Lead Authors in the ongoing process of writing the 2nd Austrian Assessment Report on Climate Change (the national pendant to the IPCC and its Assessment reports).

POPJUS researchers have also been instrumental in incorporating systems analysis elements on grand global challenges in global institutions' teaching and training courses. For example, we have been involved in co-designing "Climate Change Economics" and "Macroeconomics of Climate Change" courses for the Joint Vienna Institute (JVI) and the International Monetary Fund (IMF). These courses have become part of the most popular trainings that JVI is offering for public sector officials from countries in Central, Eastern and Southeastern Europe, the Caucasus and Central Asia and EQU researchers are frequently lecturing as part of this courses.

POPJUS is part of the steering board of the INQUIMUS Workshop series, which aims to provide exchange, new inspiration and generative dialogues in the context of comprehensive risk management. The specific role of POPJUS lies in strengthening the human dimension (e.g., focusing on subjective risk tolerance) in a field that is historically strongly dominated by quantitative methods and tools. In this capacity, EQU has hosted the INQUIMUS 2022 conference - Transformational risk management and Loss & Damage: What are suitable approaches for assessing climate-related (residual) risks? at IIASA.

Recently, POPJUS has also been instrumental in initiating a new commission on the "defossilisation and carbon neutrality of the European energy system" at the Austrian Academy of Sciences. EQU researcher Thomas Schinko has been nominated as one of the members of this commission and is leading one of the two working groups, again with the aim of establishing real interdisciplinary connections between engineering, natural and social sciences and the humanities.

6.1.3. Program budget and staff

Table 6-1 POPJUS budget 2021-2024 (Euro)

	2021	%	2022	%	2023	%	2024
Total budget	**1,508,511**		**1,859,876**		**2,075,579**		
Income from External Projects	844,885	56	1,064,646	57	1,070,025	52	not available
Income from Internal Projects	30,665	2	93,219	5	141,389	7	not available
Core allocation	632,960	42	702,011	38	864,165	42	875,730
Expenses	**1,429,116**		**1,736,104**		**1,987,814**		not available
Total FTEs	**30.29**		**35.90**		**41.24**		**41.48**
FTEs scientific	28.48		33.63		38.76		38.88
FTEs non-scientific	1.81		2.26		2.48		2.60

In the period from 2021-2024, the POPJUS staff was represented by 31 nationalities: Austria, France, Netherlands, China, Nepal, Thailand, USA, India, Italy, Germany, Indonesia, Colombia, Romania, Finland, United Kingdom, Brazil, Sweden, Canada, Turkey, Slovakia, Spain, Poland, Russia, Costa Rica, Ukraine, Iran, Bulgaria, Egypt, Australia, Japan, Switzerland.

Table 6-2 POPJUS staff 2021-2024 by FTE

	EQU	MDM	MIG	SHAW	POPJUS	TOTAL
2021						
Scientific Personnel	14.49	3.82	2.34	4.43	3.40	28.48
Non-scientific Personnel					1.81	1.81
2022						
Scientific Personnel	17.83	4.75	3.42	5.93	1.7	33.63
Non-scientific Personnel					2.26	2.26
2023						
Scientific Personnel	19.99	5.86	4.36	7.43	1.13	38.76
Non-scientific Personnel					2.48	2.48
2024						
Scientific Personnel	18.3	5.78	6.86	5.36	1	37.14
Non-scientific Personnel					2.6	2.6

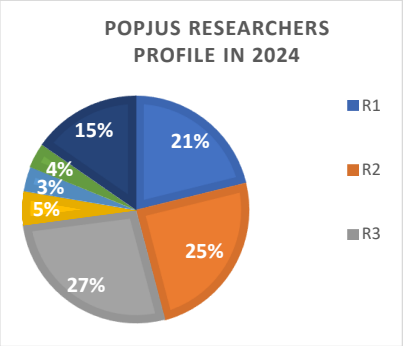


Figure 6-1 List of POPJUS Researchers in 2024

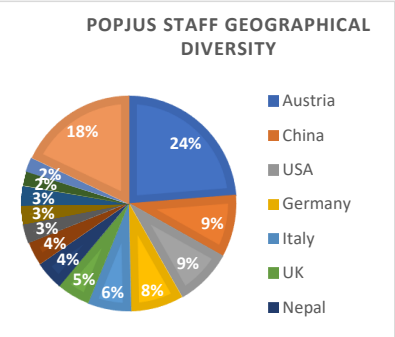


Figure 6-2 List of POPJUS Employees by Nationalities

In the period from 2021-2024, the POPJUS staff was represented by 33 nationalities: Austria, France, Netherlands, China, Nepal, Thailand, USA, India, Italy, Germany, Indonesia, Colombia, Romania, Finland, United Kingdom, Brazil, Sweden, Canada, Turkey, Slovakia, Spain, Poland, Russia, Costa Rica, Ukraine, Iran, Bulgaria, Egypt, Australia, Japan, Switzerland, Korea.

6.2. Equity and Justice (EQU)

6.2.1. Summary of achievement of goals and highlights

The IIASA Strategy 2021–2030 highlights that human beings are both the cause of dramatic global change and severely impacted by it. This leads to existential risks that are likely to cascade across interconnected socioeconomic systems and impose intolerable burdens, usually borne disproportionately by the most vulnerable who have often contributed little to the crises. At the forefront of global change research, IIASA has put such ethical questions at the heart of its research strategy. As a newly established research group after IIASA's restructuring in 2021, the Equity and Justice (EQU) Research Group at IIASA sets out to advance the justice debate in global change research and sustainability science using mixed, systems-based, and participatory methods. EQU research aims to contribute to achieving the SDGs by developing and applying conceptual and analytical frameworks for integrating equity and justice into systems analysis. Scientists in EQU bring a valued perspective to major global and local policy issues, including the climate crisis and biodiversity loss, by identifying and co-designing governance reforms and policy options that take account of diverse perceptions of procedural, distributive, and compensatory justice.

EQU's overarching goal is to establish IIASA as an international hub for conceptual, descriptive, normative, and empirical analyses to address equity and justice issues as well as resulting governance challenges in the context of applied systems analysis. To operationalize this overall goal, EQU set the following subgoals for the period 2021-2024:

- **EQU will take the lead in co-creating a conceptual and analytical justice framework for IIASA**

EQU was established in 2021 with the explicit task to create (see Figure 6-3) across disciplines and research areas, involving a variety of activities, workshops, research projects, researchers from and beyond IIASA including NMO countries, and several key publications (de Goer de Herve et al., 2023; Schinko et al., 2023; Zimm et al., 2024), EQU has recently synthesized the first version of the IIASA/EQU justice framework (Hanger-Kopp et al., 2024). The resulting IIASA

Working Paper is a descriptive framework without normative objectives. The framework is grounded in philosophy and applied and tested in a variety of applications (e.g., designing just biodiversity scenarios, developing guidance material and a tool for just mitigation scenarios, identifying justice challenges in the field of climate risk management), to be useful for research and decision making. It is meant to be accessible (across disciplines), powerful (in terms of capacity to express a variety of justice ideas), and modular (researchers can select and deploy the dimensions that are most appropriate or useful). The current framework serves as a baseline for further refinement, expansion, applications, and evaluation across disciplines, subject areas, and cultural backgrounds over the next research plan period.

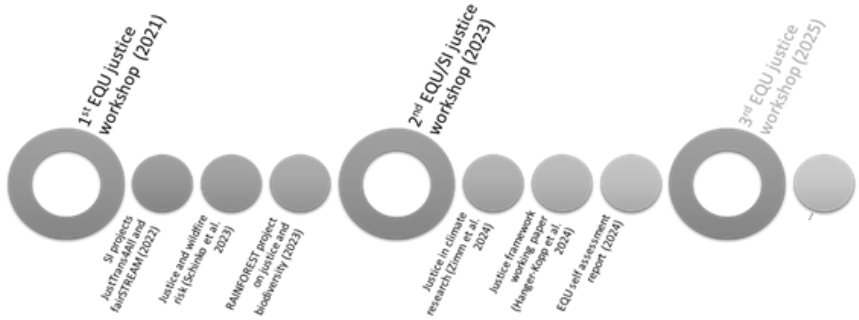


Figure 6-3 Key activities at Equity and Justice Research Group towards developing a IIASA justice framework

- **Strengthen the people-centered and transdisciplinary approach as an analytical framework at IIASA in order to assess the degree of vulnerability and resilience of diverse actors**

This goal is linked to the IIASA strategy identifying the need to understand how underlying socioeconomic inequalities and demographic pressures, individual and collective actions (i.e., values, behaviors, norms, and cultures), and the diversity of communities (e.g., rural and urban) affect possible interventions in order to enhance resilience, equity, and the sustainability of human societies. Upon its creation in 2021, the EQU group was building on strong capacities and extensive knowledge gained over the past decade in developing and applying participatory research approaches for assessing and co-designing options for multiple topical policy issues with a past focus on climate-related risks. To better understand how different actors perceive and evaluate risks and their capacity to adapt to changes, EQU engaged in several new research projects that allow us to bring an empirical, people-centered bottom-up element into our conceptual justice framework. For example, based on a broad stakeholder co-design process, we are informing decision makers in Austria about group-specific social vulnerabilities to key climate risks and thereby enabling the implementation of just and cost-effective adaptation measures as well as in-creasing adaptive capacities of private households where most needed. In another exemplary project, EQU is involved in an inter- and transdisciplinary research process of co-creating and researching essential tools and methodologies towards a drought climate risk service for Austria. Our researchers are thereby leading the development - together with potential end-users at different policy scales in Austria – of a co-creation methodology to identify the requirements of a drought climate risk service.

- **Advance applied systems analysis research in the context of procedurally just social and institutional arrangements for enabling an equitable and sustainable societal transformation**

Building on the long experience of EQU researchers in the field of governance, the group continues to explore options to support transformative governance for just and equitable societies in the context of the grand social, economic, and ecological challenges of our times. For us, procedurally just research means putting people's lived experience at the center to solve real-world policy problems that our societies face. To achieve this goal, EQU carried out various applied and empirical research activities at the interface of science, policy, and society, working at many different levels and with different stakeholders comprising e.g., international organizations like the IMF to local governments, school children, farmers in Ghana and Indian villages. Over the period 2021-2024 EQU conducted multiple transdisciplinary research projects that developed and implemented various participatory methods incorporating our expertise in applied systems analysis, governance, social science and applied empirical ethics. Amongst other, we (1) developed a Climate Peer-to-Peer Training for Austrian school students to raise awareness and increase their self- and collective efficacy in the climate crisis; (2) designed and implemented a participatory visioning workshop supporting the Styrian Government to co-design a vision for a climate resilient future with a sample of 50 representative citizens; (3) implemented Policy-Business Fora for Nature-based solutions (NBS); (4) assessed the role of insurance in establishing NBS, e.g., in the context of wildfire risk management.

- **Identify and work on strategies to rigorously attract and engage international experts in the field of applied ethics and social justice**

EQU's strategy to achieve this goal in the period 2021-2024 included recruiting ethicists as guest researchers and jointly working with them toward securing internal and external funding to support this effort. Already in 2021, we successfully recruited two established applied ethicists as EQU guest researchers who continue active collaborations with us, Ivo Wallimann-Helmer (University of Fribourg, Switzerland) and Kian Mintz-Woo (University College Cork, Ireland). Together with Kian Mintz-Woo, we successfully applied for an IIASA-internal Strategic Initiatives project "JustTrans4All". A proposal together with Ivo Wallimann-Helmer is currently under review with Austria's FWF. Both colleagues were furthermore involved in the development of EQU's Justice Framework for IIASA and they have been instrumental in connecting EQU researchers to relevant international ethics networks. In 2024 we hired Elliott Woodhouse a trained ethicist as PostDoc researcher within the RAINFOREST research project, who will focus on ethical aspects at the climate-biodiversity nexus and contribute to the further development of our Justice Framework.

Highlights of EQU scientific output and policy/societal impact

The following five highlights are closely related to our goals described in the previous section and show that EQU research is truly inter- and transdisciplinary, having scientific, policy and societal impact, often at the same time and across different geographical scales. We follow Belcher and Halliwell's (2023) complex systems approach on assessing research impact, who propose a classification of sub-categories of impact that are based on the nature of the change: **Outputs (OP)**, the products and services of research directly generated by EQU; **Outcomes (OC)**, changes in the agency or behavior of other actors, influenced by EQU research outputs; **Realized benefits (RB)**, tangible changes in the social, economic, environmental, or other physical conditions, resulting from a chain of events to which EQU research has contributed. It is important to note that change happens in a complex system of many different actors and dynamics, outside the direct control of a Research Group. Hence, EQU's sphere of direct control comprises the Outputs, while the Outcomes are situated in its sphere of influence. Eventually, the actions of influenced actors will then contribute to realized benefits in the sphere of interest, to which EQU is only indirectly linked.

#1 EQU injects justice expertise into IIASA research and beyond (OP, OC)
Within the co-creative process towards an EQU Justice Framework for IIASA (and beyond) that we started in 2021 (cf. section 2.1), EQU has not only participated in various collaborative research endeavors within (three SI projects fairStream, JustTrans4All, TRUST) and outside of IIASA, but also published key scientific papers in leading international journals (e.g., Nature Climate Change a, b and Risk Analysis). We synthesize the insights from these research endeavors in an accessible IIASA Working Paper (Hanger-Kopp et al., 2024), which comprehensively outlines justice in its multiple levels, aspects, and dimensions, facilitating justice assessment across diverse research and policy areas.

#2 EQU spearheads NBS governance and financing research (OP, OC)
EQU established itself as a leader on NBS governance, spearheading research on financing and policy options that can enable (or hinder) NBS implementation and transformative adaptation. EQU secured funding for four EU-funded projects on this topic (PHUSICOS, FIRELOGUE, NATURANCE, HuT). Six case studies were conducted in Europe and China. Particularly relevant are the production of three policy briefs, 10+ scientific publications, five project deliverables and the establishment of an interdisciplinary working group on wildfire insurance. These projects also involved organizing four international policy-business fora, four webinars attended by hundreds of people and a Finance Innovation Festival with ~100 experts.

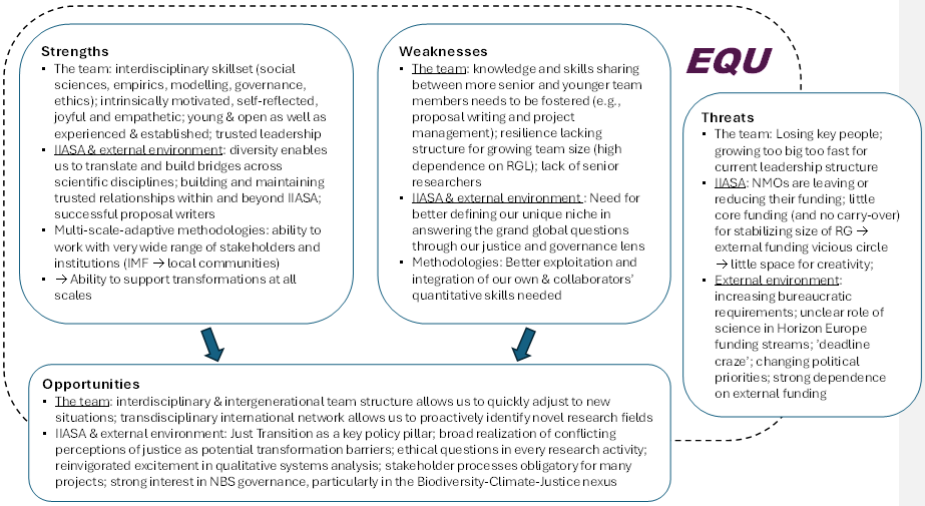
#3 EQU empowers the youth amidst the climate crisis (OP, OC, RB)
At the science-society nexus, EQU has developed a climate-peer training for schools within the makingAchange research project. The training program, which has reached over a hundred Austrian kids so far, aims to provide students not only with solid scientific facts but also soft skills that are needed for building up their own sustainability initiatives. Eventually, we want to empower the participants and provide them with a new sense of self and collective efficacy. Building on the success of the makingAchange climate-peer training and the resulting handbook, IIASA (EQU, CDAT and CER) will continue this endeavor as IIASA Climate Champions.

#4 EQU advances qualitative systems analysis methodologies (OP, OC)
EQU researchers conducted important basic research for the structured exploration of qualitative systems mapping. Systems mapping approaches have been receiving renewed attention both for conducting more transparent and systematic social empirical research as well as supporting policy-making – as they foster systems thinking, co-production of knowledge on complex problems, and communication across disciplines and policy domains. This work will strengthen ongoing methods development across a variety of EQU projects. Indeed, these methodological developments are of importance beyond EQU, as qualitative systems analysis, and system mapping specifically, are nowadays considered essential tools complementing quantitative modeling, for and beyond transdisciplinary research.

#5 EQU highlights the role of path dependencies and leverage points in climate risk governance (OP, OC)
Conceptual and applied work on path dependency in the realm of disaster risk management and climate change adaptation, expands systems analytical work that has originated in part at IIASA in the 1980s. This work is receiving international attention – both from the scientific and policy communities as path dependencies are considered a major barrier to increasing societal resilience and enabling sustainability transitions. Equally important for effective climate adaptation practice is the identification of systemic leverage points. EQU has contributed to the emerging field of interlinkages between leverage points, by focusing on food systems in Ghana and assessing how leverage point interlinkages can be exploited for strengthening adaptive capacity.

6.2.2. SWOT analysis of EQU

The following SWOT analysis was conducted jointly by EQU team members at the Annual EQU Team Retreat in May 2024.



6.3. Multidimensional Demographic Modeling (MDM)

MDM's research closely aligns with the core objectives of the IIASA strategic plan, particularly in developing robust human-centered system models for systems analysis. While the research group was established in 2021, its core activities have long been integral to IIASA's development, drawing from methodological advancements by Andrei Rogers (e.g., 1981), Nathan Keyfitz (e.g., 1980), and applications by Wolfgang Lutz (e.g., 2001) and their teams. A primary focus is on developing population projections that capture the multidimensional aspects of people's characteristics and behavior. This approach aims to provide a more accurate understanding of future world populations, crucial for assessing their exposure to socio-economic, environmental, and geopolitical challenges, their vulnerabilities, capacities, and resilience (Ghio et al. 2023). Within IIASA, MDM's unique capacity for quantitative assessment and forecasting of population dynamics facilitates this research. MDM has gained international recognition for its multidimensional projections covering 200 countries from 1950 to the end of the 21st century. These projections, encompassing various socioeconomic scenarios with regular updates, utilize a scenario-based approach aligned with frameworks like the Shared Socioeconomic Pathways (SSPs), originally devised for climate change research. Accurate assessment of population dynamics requires understanding the key drivers of change: fertility, mortality, and migration. MDM collaborates closely with MIG and other research groups at the Wittgenstein Centre for Demography and Global Human Capital—a collaborative center of the Austrian Academy of Sciences, IIASA, and the University of Vienna—to derive realistic estimates and assumptions regarding these drivers. MDM's approach involves incorporating significant sources of population heterogeneity beyond age and sex into projections, including education, labor force participation, and place of birth. This explicit focus on heterogeneity allows for realistic estimates and projections, acknowledging demographic behaviors vary across population sub-characteristics and geographical locations.

6.3.1. Summary of achievement of goals and highlights

MDM's overarching goal is to advance demographic modeling methods further, enhancing the assessment and forecasting of population dynamics with particular emphasis on social and spatial heterogeneity across global, national, and subnational levels.

To operationalize this overall goal, MDM set the following subgoals for the period 2021-2024:

Update baseline data used for population projections (when applicable)
The first set of global population projections following the Shared Socioeconomic Pathways (SSPs) was developed in 2013 (WIC2013 as documented in Lutz et al. 2014). These projections have found widespread use within the environmental and climate change community, among others. In 2018, an SSPs update was generated but not integrated into the SSP database (WIC2018 in Lutz et al. 2018). The global population projections underwent a major update through the research period 2021-2024, culminating in the release of an updated set in March 2024 (WIC2023). These projections cover 200 countries until the end of the century and include breakdowns by age, sex, and levels of educational attainment (see data sources in Figure 1), following the SSPs narratives (KC et al. 2024). To achieve this, the baseline data on population by age, sex, and educational levels was revised, alongside updates to base-year fertility data (by age and education), mortality data (by age, sex, and educational attainment), and migration data (by age, sex, and educational levels). Notably, compared to earlier versions, education-specific mortality has been tailored to individual countries and regions. Furthermore, this version introduces explicit education-specific migration differentials. This version has been validated by the SSP community and will be further as important inputs for the climate models, feeding into the Intergovernmental Panel on Climate Change (IPCC) further assessment reports as WIC2013 entered the 6th round assessment.

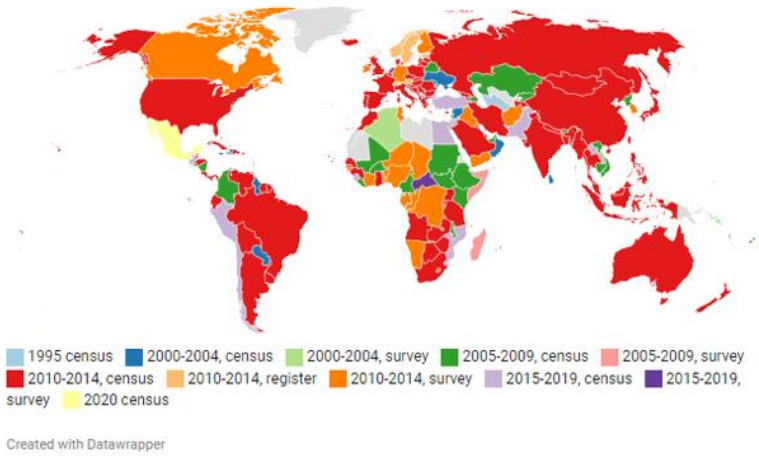


Figure 6-4 Types of data sources used in the WIC2023 dataset on population by age, sex, and education in 185 countries (for 15 countries, we used regional averages or proxy country for missing education levels).

Rigorously include new relevant dimensions in population projections (e.g., place of residence).
The WIC2023 population projections mentioned earlier represented a deviation from our 2021 work program. Originally, MDM researchers aimed to incorporate an additional variable into global population projections: place of residence, distinguishing between urban and rural areas or degrees of urbanization. However, in 2021, the SSP community requested an update on the human core of the SSPs, prioritizing factors like age, sex, and education. This demand left insufficient time to develop a new model encompassing place of residence. Nonetheless, significant progress and research have been made in that direction. Particularly, looking at the component that is the game changer in territorial composition that is international/internal migration and labor force participation. For instance, MDM researchers used microsimulation models to project the population of 31 European countries by many characteristics capturing the heterogeneity of their inhabitants: age, sex, country of residence, region of birth, immigrant status (age at migration, duration of residence), educational attainment, labour force participation, and religion, language spoken at home, in the framework of the Horizon 2020 QuantMig project. Other externally funded projects, such as FUME (in collaboration with the MIG research group) and more recently PREMIUM_EU model and analyze the socioeconomic and demographic impacts of migration. Microsimulations have also been used to project labor force participation in countries such as India (Marois et al. 2022) and China.

Apply innovative data and methods to produce population projections on smaller geographic scales
Population projections at small geographic scales are pivotal for informing local and regional planning, resource allocation, and policy development. Their significance is amplified by the uneven distribution of climate and environmental change impacts at the national level. Within the IIASA/IACC-led SPARCCLE project, initiated in 2023, MDM researchers are evaluating and projecting multi-dimensional socioeconomic vulnerabilities at NUTS2 and/or NUTS3 levels, utilizing updated Shared Socioeconomic Pathways (SSPs) and downscaling Bayesian techniques. Similar methodologies have been applied to project the sex ratio at births in Nepal (Chao et al. 2022). Additionally, microsimulations have been employed to forecast the impact of air pollution on child stunting in India, factoring in state-level and urban/rural characteristics (Dimitrova et al. 2022). These efforts underscore the critical importance of accurate, localized population projections in addressing complex socio-environmental challenges and fostering targeted interventions for vulnerable communities.

Improve and update assumptions related to future population trends
Global population projections are primarily based on models taking into consideration past trends but also consider expert opinions for the assumptions. The first global population projections developed at IIASA (WIC2013) used the result of an expert survey that was conducted in 2010-2011. In 2022-2023, initiated by the European Commission Joint Research Centre and in collaboration with the United Nations Population Division, who is one of the major global projection producers, MDM launched a survey (Icardi et al. 2023) where experts were asked to assess the validity and relevance of alternative arguments about the forces that could shape future fertility, mortality, and migration trends in the country of their choice. The survey also included a section on the potential consequences of demographic change for policy. It brings interesting results that will be used in the next round of population projections foreseen for 2028. The expert opinions seem to indicate that the demographic challenges of the future may not always have straightforward demographic solutions that make it even more crucial to embed demographic modeling in IIASA research. The survey was presented in different settings with dialogues with policy makers and researchers.

MDM Highlights of scientific output and policy impact

- **Updating the Shared Socioeconomic Pathways (SSPs) Global Population and Human Capital Projections**

The SSPs are an important input for the latest climate models, feeding into the Intergovernmental Panel on Climate Change (IPCC). They are also being used to explore how societal choices will affect greenhouse gas emissions and, therefore, how the climate goals of

the Paris Agreement could be met. By providing data on education, they provide a valuable input to multiple international policy stakeholders (e.g., World Bank, OECD, Population Council, European Commission) and researchers.

- **Anticipating and responding to emerging issues: Ukraine's population future after the Russian invasion and the impact of COVID-19**

While MDM's plan was outlined in 2020-2021, the research group responded to several challenges that emerge during the last few years. First, studying the global COVID-19 crisis and its impact on migration at different international (e.g., REF) and national levels (e.g., REF), on repercussion of school closure on future skills (REF), and on health (mental and physical) and mortality (REF). The second emergency was linked to the invasion of Ukraine by Russia and the displacement/migration of several millions Ukrainian outside of the country and particularly to Europe, for which modeling was used to explore the potential futures.

- **Better modeling migration and its impact (QUANTMIG and FUME project)**

In collaboration with the MIG research group, the different research streams aimed at better estimating migration flows and stocks, developing scenarios about projections of internal and international migration flows and their impact on population change. These projections provide the migration components of the SSPs but also

- **Demographic Expert Survey on the Drivers and Consequences of Demographic Change**

The result of the 2023 Demographic Expert Survey lead to rich dialogues around its results at several levels. The expert opinions seem to indicate that demographic challenges of the future do not necessarily have demographic solutions, which was debated from several angles at conferences: Population Association of America (PAA) and at the European Population Conference (EPC) in 2024. It was also debated at the European Commission level in a workshop involving researchers and policy makers. The dialogue is important because we will reflect on how the findings can shape future global population projections.

- **Population exposure and vulnerabilities, and environmental feedback to population change**

There is a growing cluster of projects that link population and climate change, whether looking at the energy-fertility nexus, that is key for population stabilization in Global South countries, exposure and vulnerabilities to climate change (SPARCCLE in the context of Europe, or in the context of Africa), or on the consequences for the economy of the arrival of a large wave of climate migrants in the case of Austria. We foresee that the body of research work and projects on the topic of interactions between population and climate change will increase in the MDM group.

6.3.2. SWOT analysis of MDM

Strength	**Weakness**
• The multidimensional population modeling and projection research in the MDM RG is a **niche**. • It offers **potential for development** with the inclusion of more/different socioeconomic variables, at varied spatial level. • The MDM team is **committed** to common goals. • There is **diversity** in the team with both **specialized** and **complementary** profiles and skills (statistics, qualitative & quantitative researchers, multistate population projections, microsimulations, etc.). • MDM is becoming increasingly **visible** within IIASA and outside of IIASA.	• **Funding opportunities** for standing-alone population projections/modelling do not exist – hence the need to depend on others' need for population modelling. • While in the plan, t**he multidimensional model is not set for training and distribution,** which still limits its spread. • Small team which would require more modeling expertise. • More work is needed on making the **models endogenous with feedback effects.**
Opportunities	**Threats**
• **Funding Opportunities** emerging from the fact that population modeling is an input for multiple projects, that MDM can provide with heterogeneity (socioeconomic and spatial). • **Collaborations** within IIASA with ASA and ECE in particular, and outside of IIASA, for instance with the European Commission Joint Research Centre, the World Bank, the UNFPA, Asian Demographic and Research Institute, United Nations Population Division. • **High-impact publications** are possible with global population projections and other research modeling projects. • **Technology Transfer potential**: Develop the MDM population projection model to become available online. • MDM attracts **early career researchers** (YSSP, post-docs) helping in spreading the modeling philosophy. • **MDM's r**esearch findings by addressing societal challenges inform policy decisions. MDM has engaged in dialogues with political stakeholders at the international and national level.	• **External funding:** time needed to apply for more research projects; understaffed; not the capacity to deliver; bad for our reputation. • **Professional uncertaintie**s: difficulty keeping the staff; discontinuity in projects. • **Growing bureaucratic monster:** Taking time away from relevant research, and not receiving enough benefits in return in terms of services. • **Institutional memory:** person brand more than institution brand: e.g., the MODGEN microsimulation tool.

6.4. Migration and Sustainable Development (MIG)

The MIG research group 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 considering its interactions with the social, economic, and environmental dimensions of sustainable development. A key emphasis has been placed on understanding the heterogeneity of migration, considering demographic, spatial, and other relevant characteristics.

6.4.1. Summary of achievement of goals and highlights

The MIG group has focused on achieving four goals over the period 2021-2024 using a combination of advanced migration modeling, novel data sources, and forecasting approaches.

- **Continue to improve migration estimates by employing novel data and innovative methods.**

Over the past 4 years, MIG has produced a range of novel data sources that have provided the basis for enhancing the estimation of international and internal migration, including patterns, drivers, and impacts. Whenever possible, data were published open access following FAIR data sharing principles to ensure transparency and to allow other researchers, policymakers, and stakeholders to analyze, validate, and expand the data. Building on previous work on estimating bilateral international migration flows worldwide (1990-2015), the group has developed international migration flow estimates broken down by sex and by age, sex, and educational attainment (in collaboration with MDM research group). These provide valuable information on differentiated patterns of migration of population groups across different world regions. In another study, the group has advanced the reconstruction of age-specific migration flow estimation using Bayesian modeling to address issues in migration flow estimation related to small sample sizes and demographic heterogeneity (e.g., when estimating age-specific migration flows between small countries). Building on work carried out jointly with the MDM research group as part of the Horizon Europe funded project Future Migration Scenarios for Europe (FUME), the group has enhanced the estimation of migration stocks and flows to Europe enriching existing estimates using new temporal definitions and integrating various data sources.

MIG has also explored the use and applicability of non-traditional data sources in migration estimation, including digital trace data derived from social media (Yildiz et al., paper forthcoming in International Migration Review). In addition to novel international migration estimates, the group has developed novel comparative datasets estimating internal migration, building on census data for 72 countries derived from the Integrated Public Use Microdata Series (IPUMS) International. The latter data provide rich information on migration between subnational regions within countries at administrative level 1 and 2. Even greater detail is provided in two novel migration datasets developed by MIG members which estimate net-migration between 1990 and 2000 and net-migration between 2000 and 2019 at a high spatial resolution combining birth and death rates with overall population growth at the grid level (10km resolution) to estimate net migration. The data reveal complex patterns in net-migration worldwide which are closely linked to socioeconomic developments across regions. The various migration datasets can be combined with other global datasets produced by the group which map sustainable development processes and changes in livelihood conditions building on harmonized Demographic and Health Survey (DHS) data.

- **Advance understanding on the changing nature of the drivers of migration**

In the past years, global change processes and crises have shaped migration patterns worldwide. These include impacts of the Covid19 Pandemic, geopolitical instability and wars, and different extreme climatic events and disasters. Through its work, MIG has contributed to advancing the evidence on the role of these factors and the changing nature of migration drivers in different parts of the world. A major part of the group`s work has been focused on the impacts of climatic changes and environmental hazards on human mobility generating a major scientific and policy impact, including through: (1) synthesis studies using meta-analysis and systematic review methods, (2) large-scale global analyses using subnational census and grid-

level data, (3) case studies providing in-depth perspectives into climate mobility in local contexts, among others in Tanzania, India, Indonesia, (4) the analysis of heterogeneity in migration responses to environmental stress, (5) the exploration of the role of migration as an adaptation strategy and translocal social resilience dimensions of migration as adaptation, (6) the microeconomic modeling of household mobility decision making in disaster contexts, (7) work on how the science-policy interface in the field can be strengthened, and (8) issues with climate resilience of migrant and non-migrant households in migration destination areas. For affected households, migration can lead to improvements in their livelihoods, but there may be limits to adaptation and in many contexts, immobility may occur, either because households decide to stay put, or because they are forced to despite difficult circumstances. In addition to emerging environmental drivers, the work of the group has contributed evidence on conflict-driven forced migration and the role of compound risks in shaping mobility, including highly-cited global analyses on the climate, conflict, and migration nexus, and case studies from Somalia and Columbia (Fenz et al, forthcoming Vienna Yearbook of Population Research). Finally, together with the MDM research group, MIG researchers have quantified the impact of COVID-19 on immigration in high-income countries, highlighting the important role health crises can play in shaping global mobility patterns.

- **Update baseline migration data for population projections**

MIG has provided critical inputs to the updates of the global population projections carried out as a joint effort by the Wittgenstein Centre for Demography and Global Human Capital of which IIASA's Population and Just Societies Program is one pillar institution. For this, MIG has produced updated global migration data and estimates, including updated international migration flow estimates. In addition, more refined datasets by relevant population characteristics were produced that allow for a more granular perspective on international migration, distinguishing migration flows by sex, and by age, sex, and educational attainment. These data inputs have been used, among others, for the development of novel migration scenarios to update the population and human capital components of the Shared Socio-Economic Pathways (SSPs) projections, which also form the basis of the Wittgenstein Centre global population projections.

- **Improve and update assumptions related to future migration trends**

In addition to empirical analyses of past migration and relevant drivers, the development of enhanced migration forecasts and projections represents one of the key achievements of the group. For this, the MIG team has collaborated with the MDM research group to improve and update the assumptions related to future migration trends and to develop novel migration projections based on different socioeconomic scenarios, which were used an input to the update of the Shared Socioeconomic Pathways (SSPs) and Wittgenstein Centre population projections. As part of the collaborative FUME project, new migration scenario narratives for Europe were developed, and the narratives were quantified in form of novel migration scenarios taking into account changing drivers and their relevance for migration to Europe (Yildiz et al, forthcoming in Demographic Research). Further work of the group has focused on improving the estimation and forecasting of bilateral migration between South America and Europe (in review). As part of the PREMIUM-EU project, led by the MDM research group, members of the MIG group have further contributed to providing evidence and scenarios on migration to Europe and the role of policy for turning the individual benefits of mobility into societal benefits. At the global level, the group has contributed to the development, implementation, and analysis of the Global Demography Expert Survey as part of which 237 experts were interviewed to gain informed insights into the future of the world population and population dynamics, including migration. Insights from the survey will be used to further enrich MIG's migration scenarios in the future and to advise policy. Further work of the group has focused on the role of information campaigns in shaping local perceptions and discourses of migration, and in influencing migration aspirations. Such information campaigns have been increasingly used in migration policy, and may be a relevant factor in shaping future migration trends. Also societal transformations and change processes can have a major impact on future migration, which is the focus of MIG's Sustainability Performances, Evidence, and Scenarios (SPES) project funded by the European Union.

Highlights of MIG scientific output and policy impact:

(1) Migration in times of global environmental changes and crises
MIG's work has significantly contributed to improving the understanding of the climate-environment-migration nexus. The group has carried out large-scale empirical analyses at the global and regional level to explore the complex interplay between climatic risks, moderating influences and mechanisms, and migration (e.g. studies in Global Environmental Change, Nature Communications, Nature Human Behavior, Nature Climate Change). By integrating georeferenced migration and environmental data across multiple scales, MIG has provided valuable insights into the spatial and temporal dynamics of climate migration, highlighting its potential for adaptation processes as well as pertinent risks and challenges for affected households and communities.

(2) Advancing migration data and estimation
Advances in data represent one of the key scientific outputs of MIG's work in the past years. In addition to providing updates on existing datasets on international migration, the group has produced a series of novel datasets allowing to distinguish migration flows by demographic subgroups. The data on international migration are complemented with novel datasets capturing internal migration sub-nationally as well as migration at a high spatial resolution at the grid level. Digital traces have been used to enrich traditional sources for migration estimation. Integrative methodologies (e.g., Bayesian modeling or machine learning) were used for estimation, including in data scarce contexts.

(3) Migration forecasting and population projections
The novel migration data and evidence produced by MIG have formed the basis for the development of new migration scenarios providing valuable insights into future migration of relevance for policy and strategic planning. To further enrich the scenario formulation and to gain a comprehensive perspective on future trends, a Global Demographic Expert Survey was carried out and analyzed under the leadership of the MDM team. Scenarios on future migration were used as an integral input to the updates of the population and human capital components of the Shared Socio-Economic Pathways (SSPs), which are widely used by the scientific community.

(4) Generating policy impact
MIG has achieved lasting policy impacts through its involvement in different policy fora and events, including a migration conference organized by the European Commission, a policy workshop on understanding migration drivers for policy development, and a G20 task force on migration. In addition, the group has contributed to various reports, including on environmental change, conflict, and human migration by the Mediterranean Experts on Climate Change (MedECC) and on human migration and natural resources: global assessment of an adaptive complex system" by the International Resource Panel (IRP). The group has also been collaborating with various policy actors and international organizations, including the World Bank, OSCE, OECD, UNFPA, IOM, and UNICEF.

(5) Public outreach, capacity building, and awareness raising
In addition to an academic audience, MIG has also actively engaged with the general public to broaden its impacts and to raise societal awareness and knowledge on migration. Relevant highlights from our work in this area include the organization of a IIASA Voices Webinar (2024) on emerging migration drivers, the co-organization of the Wittgenstein Centre conference (2022) on "population and climate change", and a TEDx talk (2023) on climate change and population dynamics. Several members of the group are also actively involved in capacity building activities and teaching, among others at the University of Vienna, different summer and winter schools, and community colleges in Austria.

6.4.2. SWOT analysis of MIG

Strengths	**Weaknesses**
• Expertise in empirical, quantitative migration research and modeling. • Strong methodological background and rigor • Access and expertise to unique and innovative migration data • Reputation in the analysis of migration in response to (global or local) changes and disruptive events • International networks and connections to scientists in various disciplines • Highly qualified group of researchers with diverse background and experiences combining multiple perspectives (bottom-up interdisciplinarity) • Good research ethics • Good atmosphere, management, and support in the group • Supportive environment at IIASA. Institute infrastructure for publishing data and dissemination of research outputs	• Dependency on external funding and budgetary uncertainty • Lacking theoretical work and contributions to the broader migration literature that go beyond empirical results and modeling • Lack of group cohesion given that many group members also work in other institutions, including on topics other than migration and sustainable development • Group could more strongly use qualitative research and think more about political narratives on migration • Lack of visibility and "brand name" given that MIG is relatively young, there is limited recognition of IIASA and MIG as a hub for migration research. • Lack of exposure to on-going migration research outside of our personal network and research topic "bubbles" beyond conferences
Opportunities	**Threats**
• Increasing importance and salience of migration as a research topic. • Strong international networks to cooperate with researchers from research groups with a stronger theory and/or policy focus. • Creating a distinct group profile / niche, pursuing more focused research and hiring, targeted projects, and strategic collaborations. • Potential of developing a broader group profile that goes beyond individual contributions and establishing MIG as a prominent hub for migration research both within IIASA and in the wider academic community worldwide. • Strategic collaborations with partners from policy and practice. • Novel data sources, including Austrian micro data, could open new research possibilities. • Further embracing supportive management through retreats, seminars, workshops etc.	• In the long run, maintaining a consistent research focus and high group cohesion is challenging in a research environment where most contracts are short-term and temporary in nature. • Migration is a popular topic and many other researchers are working on it as well. • Budgetary uncertainty within IIASA. Challenges related to "normatively-directed science funding". • Maintaining a clear research focus of the group while at the same time integrating the diverse interests of the group members.

6.5. Social Cohesion, Health and Well-being (SHAW)

The SHAW group (hereafter SHAW), dedicated to advancing human wellbeing with a particular emphasis on health, identified three goals guiding its research over the period 2021-2024, pursued through interdisciplinary approaches: 1) developing new methods for wellbeing measurement and healthy aging; 2) examining the relationship between the environment and health outcomes; 3) understanding the drivers of health and wellbeing across contexts and population subgroups.

6.5.1. Summary of achievement of goals and highlights

1. Continue to **improve the measurement of human wellbeing** accounting for population heterogeneities

A key achievement was the development and testing of a novel measure of wellbeing, the Years of Good Life (YOGL) indicator. YOGL integrates life expectancy with subjective and objective wellbeing measures, enabling the assessment of wellbeing, and progress towards sustainable development, across nations and timeframes. Extensive cultural acceptability testing in Nepal, South Africa, and Costa Rica underscored its adaptability across diverse contexts. A further example of SHAW's contribution to holistic wellbeing measurement was its input into defining universal decent living standards to achieve basic human wellbeing, in collaboration with other IIASA research groups.

SHAW has also undertaken research to define globally relevant measures of healthy aging. An example is SHAW-led research showing that hand grip strength can be used as a predictor of mortality risk in clinical practice; and participation in a research collaboration which developed the ATHLOS scale for measuring healthy ageing, combining intrinsic capacity and functional ability items. SHAW research on an alternative way of conceptualizing and measuring individual and population level aging, based on prospective longevity is also noteworthy, resulting in the introduction of new UN measures of aging.

2. **Consider socioeconomic and environmental impacts and feedback on health and wellbeing,** focusing particularly on both short- and longer-term impacts of such emerging challenges and threats differentiated by population subgroups and geographical locations.

In collaboration with other IIASA research groups and external institutions, SHAW has contributed evidence quantifying the association between environmental factors and population health and wellbeing over the life course, facilitated by linking environmental and health-related data. Examples of this include a study (in collaboration with Vreije Universitat Amsterdam) exploring the relationship between air pollution and population cognitive health. This demonstrated how PM10 exposure is associated with worsened episodic memory among older Europeans.

SHAW research also examined how climate exposures affect access to modern amenities, education, and fertility rates across 52 countries. Together with IIASA's Economic Frontiers Program, research is underway to examine health effects across a range of conditions using the Global Burden of Disease data. Research in Brazil and Zambia, in collaboration with IIASA's SYRR group, is quantifying the relationship between floods and heatwaves and maternal and child health care use.

Analyses of the relationship between the environment and health are facilitated by linking environmental and health-related data, and SHAW has contributed to this by generating, and making publicly accessible, the LivWell database combining Demographic and Health Survey data with climate-related data (on temperature extremes, humidity, precipitation and drought), enabling national and subnational level analysis over the period 1990-2019 for 52 countries. Health and wellbeing, in addition to being impacted by environmental change, can also mediate the impacts of these changes, as shown in a study of the interactions between environment, mortality, and economic activity, that SHAW contributed to.

In addition to considering how environmental factors affect health and wellbeing, SHAW is also examining how social factors affect health. The Cognitive Health in Aging Society (CHIAS) project, co-led by SHAW researchers, is exploring how labour force participation, retirement, grandparenting and social network affect cognitive health and ageing in Europe, and how this varies by gender and education. Initial findings suggest that social network positively moderates the association between non-employment and episodic memory scores.
Beyond examining historical drivers of health and wellbeing it is also important to look forward and explore future scenarios on health and wellbeing. As an input into the IIASA 50-year Flagship report, the YoGL wellbeing measure was integrated into the Full of Economics and Environmental linkages and Integration (FeliX) system dynamics model to map out the impact of alternative development pathways on wellbeing.

3. **employ relevant and innovative methods** to investigate trends, determinants, and mechanisms of good health and wellbeing over time and over a life course for differentiated subgroups of populations around the world, including the effect of policies and prevention strategies.

The final area of SHAW work was centered around the exploration of trends and determinants of health and wellbeing overtime, and exploring population heterogeneities, policy, and Covid-19 impacts. In relation to understanding drivers of wellbeing, SHAW used "Years of Good Life" (YoGL), to describe wellbeing heterogeneities by country and by gender for the population aged 50+ in 26 European countries. Further work is currently underway to explore trends in cognitive abilities by age and overtime. SHAW researchers also undertook a study on health and well-being among older adults, illustrating how healthy life expectancy relates to working life expectancy in Europe, and heterogeneities by education.

SHAW has also been evaluating the effect of policy reforms on health and wellbeing, including the redistributive effects of pension reforms (Sanchez-Romero et al 2023); the impacts of social security reforms in heterogenous aging populations (Sanchez-Romero and Fürnkranz -Prskawetz 2023); and the role of financial incentives in antibiotic prescription patterns in Austria (Stacherl et al 2023).

Lastly, SHAW has contributed evidence on the health and wellbeing impact of Covid-19, including: measuring excess mortality from Covid-19 in Russia and Italy; demonstrating the limitations of tracking the case fatality rate as an indicator of pandemic impact; determining optimal lockdown intensity; and proposing a novel method to assess the impact of the Covid-19 pandemic on life expectancy.

In summary, SHAW's endeavors over the past four years have not only advanced our understanding of human wellbeing and healthy aging but also provided actionable insights for policy and practice. By integrating interdisciplinary approaches and fostering collaborations within IIASA and beyond, SHAW has made significant strides towards its overarching goal of promoting holistic health and wellbeing worldwide. Going forward, the group aims to expand its research on climate change and health, wellbeing and healthy aging in collaboration with other groups at IIASA. It also seeks to undertake further research in, and in collaboration with, the Global South.

Highlights of SHAW's scientific output and policy impact:

1. **YOGL -** Attempts at comprehensive quantitative assessments of sustainable development can focus on either determinants or constituents of long-term human well-being. While much research on determinants has relied on economic concepts of capital and inclusive wealth, this study focused on the constituents of well-being using a demographic approach. The Years of Good Life (YOGL) based on life expectancy and indicators of objective and subjective well-being enables comparisons across countries and over time, enabling the

assessment of cross-sectoral policy impacts towards achieving the sustainable development goals. It has also been combined with scenarios addressing future changes including feedback from environmental change (Lutz et al. 2021).

2. **Hand grip and health** - The paper's contributions in defining low handgrip strength related to mortality risk, providing cut-off points, and estimating remaining life expectancy have significant implications for informing healthcare policies aimed at **improving early risk detection and patient outcomes. The findings suggest that medical** practitioners should be concerned about mortality risks even when hand grip strength is slightly below the reference group, indicating the need for early interventions and monitoring for patients with lower hand grip strength levels (Scherbov et al. 2022).

3. **Working life expectancy** - This study investigated whether there is health potential for working longer given the rise of retirement ages across Europe. The study compared working life expectancy (WLE) with health specific life expectancy relevant for active labour market participation such as good cognitive and physical functioning. While life expectancy in good physical health is at a high level for 60–69-year-old, WLE and life expectancy in good cognitive health were found to increase over time. However, substantial disparities based on educational levels were identified, along with the potential to extend working lives for different educational strata (Weber et al. 2022).

4. **Demographic change and urban health** – This study aims at highlighting key linkages between demographic changes and urban health from a multifaced perspective. For instance, demographic change has a strong impact on urban health. Further, demographic processes contribute to (intra)urban inequities in health, but they could also present opportunities to address those inequities. The paper also sheds light on research gaps as well as data gaps relevant for future strategies (Duminy et al. 2023)

5. **Optimal lockdown strategies for Covid-19** - This paper examines the optimal intensity and timing of lockdown measures during an epidemic, using an optimal control model, considering the epidemic intensity and healthcare system capacity. It identifies four main lockdown strategies, from short-term lockdowns to sustained measures preventing health system overload. The model suggests returning to lockdown after lifting restrictions can be effective. The findings underscore the complexity of COVID-19 policy-making (Caulkins et al. 2021).

6.5.2. SWOT analysis of SHAW

Strengths	**Weaknesses**
• Ability to attract funding from excellent funders • Interdisciplinary • International collaborations/network • Excellent quantitative skills • Strong publication record in high impact journals • Forward looking research • Outcome focused, hence a connector to all IIASA research • Policy engagement and impact • Subject matter expertise on aging, cognitive research, YOGL/wellbeing measurement, health systems- from a global perspective	• Diverse group focusing on many topics, lacking a unique brand/focus • SHAW needs to position itself within the institution and beyond • Limited research on the climate and health/wellbeing interface • Could do more to pull out the policy impact/implications of the work • Potential for wider use of mixed methods, co-production, systems thinking tools which are in high demand by funders • Small team size, young members
Opportunities	**Threats**
• Young team, room for growth • Gain more visibility within IIASA and beyond by becoming the go-to group for health/wellbeing/health systems-related research • Consider potential re-branding of SHAW, to emphasize health/wellbeing focus • Leverage growth in funding for interdisciplinary climate and health research • Expand work on climate and health to capitalize on funding opportunities and IIASA's core strengths • Take advantage of capacity building training in CDAT • Greater use of NMOs for policy impact and outreach • Enhance cross group/programme collaborations within IIASA	• Institutional constraints to cross group/programme collaboration • Staff turnover due to breaks in funding • More competition for funding from the global south

The complete report of the Population and Just Societies Program is available at the following link: POPJUS Self-assessment report 2021-2024.

7. Program: Strategic Initiatives (SI)

The IIASA Strategy 2021–2030 aims to "collaborate with NMOs/RMO to identify Strategic Initiatives that interest multiple countries, focusing on critical themes or ecoregions to find long-lasting solutions with significant policy impact. These initiatives should benefit from systems science methods and multilateral approaches". To fulfill this and other institutional goals, the Strategic Initiatives (SI) Program was created in 2020 with the following terms of reference:

- Leverage cross-program expertise and expand IIASA's research portfolio beyond that identified in research plans of other programs.
- Lead to high strategic impact scientific outputs.
- Be a vehicle to better align NMOs/RMO and IIASA's research interests, albeit with a clear focus on themes identified in IIASA's strategy.
- Act as a magnet for external co-funding.
- Be set up via a formal call for proposals with a defined selection process and evaluation criteria.

The sections below explain the objectives in more detail and describe the extent to which these objectives have been met since the SI program's establishment.

7.1. Objectives

Leverage cross-program expertise and expand IIASA's research portfolio beyond that identified in research plans of other programs

The SI Program:

a) aligns with the IIASA strategy involving external partners when necessary to address research gaps and areas not covered by other programs;
b) represents at least two programs;
c) allows IIASA to respond agilely and flexibly to new and emerging needs; and d) strengthens inter- and trans-disciplinary research at IIASA.

Since its inception in 2020, four Strategic Initiatives have been selected through a competitive process to meet these objectives: fairSTREAM, JustTrans4All, RESIST and TRUST. These projects involve 39 IIASA researchers from various backgrounds in the natural and social sciences, representing five IIASA programs: the Advancing Systems Analysis Program (ASA); the Biodiversity and Natural Resources Program (BNR); the Economic Frontiers Program (EF); the Energy, Climate, and Environment Program (ECE); and the Population and Just Societies Program (POPJUS) (Figure 7-1 Distribution of researchers conforming the *four* Strategic Initiatives: fairSTREAM, JustTrans4All, RESIST and TRUST, in terms of which IIASA Programs (left) and Research Groups(right) they belong to.). Detailed descriptions of these initiatives and their collaborations are provided in the Research Group Activities section.

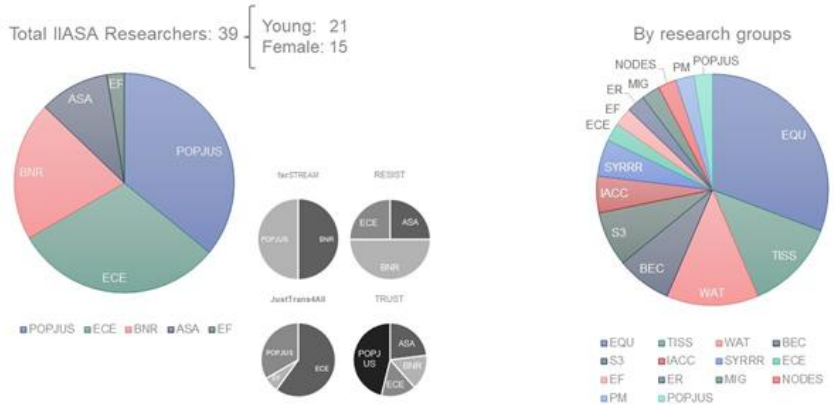


Figure 7-1 Distribution of researchers conforming the four Strategic Initiatives: fairSTREAM, JustTrans4All, RESIST and TRUST, in terms of which IIASA Programs (left) and Research Groups(right) they belong to.
Note: The gray scale pie charts in the middle show the collaboration across IIASA programs within each Strategic Initiative, resulting from the creation of the SI Program.

Lead to high impact scientific outputs

The SI projects aim to challenge existing boundaries on current and emerging priority issues through innovative research. They are designed to produce publications for high quality journals and, as much as possible, to have significant policy or societal impact.

The research outputs have gained visibility at relevant high-impact global conferences and events. Since the SI Program's inception, sixteen articles have been published, many in high-impact journals, as listed in the References section. The policy impact and other outcomes from participation in various academic and policy networks are detailed for each Strategic Initiative in the Research Group Activities section.

Be a vehicle to better align NMOs/RMO and IIASA's research interests, albeit with a clear focus on themes identified in IIASA's strategy

The SI Program was established to foster closer engagement with NMOs/RMO and better align their research interests with those of IIASA. Each SI project is designed to be valuable and interesting to multiple NMOs/RMO. During 2020-2021, a system was developed to prioritize research areas that reflect NMO/RMO interests while aligning with IIASA's strategic priorities. This system ensures representation of diverse Member interests within a defined budget. Each step of this process included at least one NMO/RMO workshop (**Error! Reference source not found.**).

Table 7-1 NMOs/RMOs Engagement

Date	Workshops	Objectives
4 December 2020	First SI NMOs consultation workshop	Survey NMO preferences to identify research themes for the funding call.
2 February 2021	Second SI NMOs consultation workshop	Survey NMO preferences to identify research themes for the funding call.
23 June 2021	Third SI NMOs consultation workshop	Allow for an opportunity to contribute additional co-funding resources to the two chosen Strategic Initiatives, fairSTREAM and JustTrans4ALL.
27 January 2022	Fourth SI NMOs/RMO engagement workshop	Discussion of Expressions of Interest between 2022 SI applicants and NMOs/RMO
17-18 Oct 2023	Fifth NMOs/RMO engagement workshop	Survey NMO preferences to identify research themes for the funding call, updating those from past workshops.
1 March 2024	Sixth NMOs/RMO engagement workshop	Present detailed projects to NMOs/RMO toward a co-design of full project proposal
September 2024 (day to be defined)	Seventh NMOs/RMO engagement workshop	Further align the SI process with NMOs/RMO interests

Throughout this process of NMO/RMO engagement, the yearly SI call cycle was gradually refined to include NMOs/RMO throughout most of the process, as shown in Figure *7-2*.

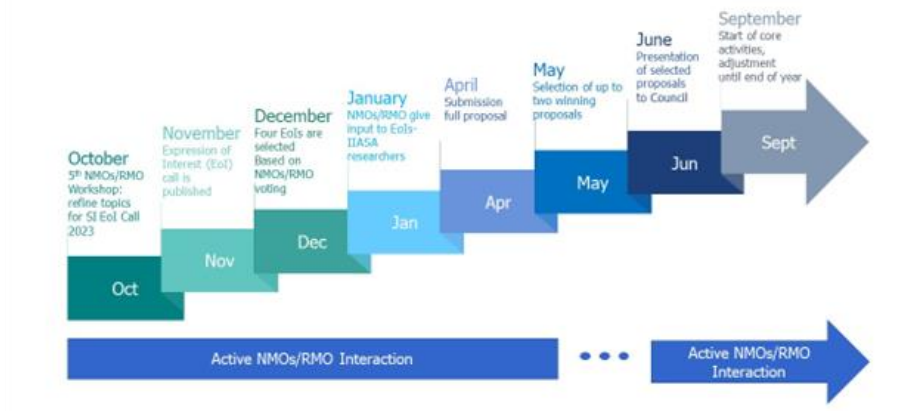


Figure 7-2 SI Program timeline for 2023, including more NMO/RMO interaction with IIASA researchers: NMOs/RMO were allowed to propose new topics, voted for the submitted EoIs and co-developed project proposals

Act as a magnet for external co-funding

A Strategic Initiative starts with program funding but should be innovative enough to potentially attract funding from external sources, either at the outset or during project development. The outcomes, including in-kind collaboration and participation in NMO/RMO national funding cycles, are presented in the Research Group Activities section, for each respective SI project, where applicable.

Be set up via a formal call for proposals with a defined selection process and evaluation criteria

A Strategic Initiative is set up via a competitive, rigorously scrutinized internal call for proposals that is announced periodically (Figure 7-2). The design of an SI should be such that participation should be a coveted activity. All SIs are time-bound and have a defined duration within the SI Program, with the intent of supporting a dynamic set of SIs that can maximize disciplinary focus. Figure 6 illustrates the evaluation criteria, reflecting the initial objectives from the Terms of Reference as well as additional selection criteria.

Evaluation Item	Overall Score 16
Ground-breaking nature and potential impact of the research project	*Subtotal: 4 points*
• To what extent is the proposed project of strategic interest to IIASA?	
• To what extent are the objectives ambitious and beyond the state of the art (e.g., novel, ground-breaking, innovative)?	
• To what extent does the proposal have a strong policy/societal impact (see under proposal section "c")?	
• To what extent is the proposed project systemic, multi- or transdisciplinary?	
Scientific Approach	*Subtotal: 4 points*
• To what extent is the outlined scientific approach feasible?	
• To what extent is the proposed research methodology and working arrangements appropriate to achieve the goal of the project?	
• To what extent does the proposal involve the development of a novel methodology?	
• To what extent are the proposed timelines, resources, and PI commitments adequate and properly justified, does the percentage of working time of the PI and team members correspond to the tasks?	
Intellectual capacity of PI and team	*Subtotal: 4 points*
• To what extent has the PI of the Initiative as well as the team proposed demonstrated the ability to conduct ground-breaking research?	
• To what extent do the PI and the team have the required scientific expertise and to what degree is the proposed project cutting across IIASA's groups and programs?	
NMOs/RMO engagement and open access	*Subtotal: 4 points*
• To what extent is the proposed project of regional or global relevance (more than 1 NMOs/RMO country)	
• To what degree do NMOs/RMO engage in the proposed project?	
• Have NMOs/RMO committed any co-funding?	
• Does the proposal convincingly demonstrate that data and models used will be free and open?	

Figure 7-3 Evaluation criteria of a Strategic Initiative Project

Since its start, the SI Program has emphasized offering project coordination and management roles to foster professional growth for young and mid-career researchers, with a particular focus on supporting female researchers. As depicted in Figure 1, roughly half of the researchers

involved in the Strategic Initiatives are early-career researchers, and nearly half of them are female. It's worth noting that the percentage of female researchers in SIs exceeds that of IIASA overall. Furthermore, three SI projects are led by female Principal Investigators (PIs), with one SI project having a female Co-PI.

Research Group Activities

The SI Program differs from other IIASA Programs as it does not have research groups; instead, it comprises Strategic Initiatives or projects selected through an internal competitive process (refer to Figure *7-3* Evaluation criteria of a Strategic Initiative Project). An outline of these projects is shown in Table 7-32. Subsequent sections detail the activities of each project, illustrating how they contribute to the Strategic Program objectives outlined earlier.

Table 7-2 Overview of the Strategic Initiatives

Strategic Initiative	Budget (Euros)*	Start-End	Participating Programs	Researchers*	Articles Published	Publications in preparation
fairSTREAM	400 K	2021-2024	2	16	4	4
JustTrans4ALL	400 K	2021-2024	3	14	9	7
RESIST**	360 K	2023-2025	3	8	4	2
TRUST**	360 K	2022-2025	4	8	0	6

* Each Strategic Initiative (SI) is funded from the IIASA Core budget through a dedicated allocation within the SI Program. However, IIASA researchers involved in each SI remain part of their original IIASA Program and Research Group, concurrently engaging in other projects and activities within these groups. Consequently, resources and funding are shared between each SI and its corresponding Research Group. This sharing may encompass administrative support or the involvement of other researchers in the project who are not funded by the SI. Therefore, it is challenging to directly measure the impact of the budget, the number of participating researchers, and the outcomes (such as published articles) based solely on Table 7-2.
** In early 2022, the budget for the Strategic Initiatives Program was adjusted due to preventive actions taken by IIASA following the Russia-Ukraine conflict. As a result, the award for winning projects in the call for proposals was reduced from $400K to $360K, and there was no call for proposals throughout 2022.

The following sections describe in detail the achievements of each funded Strategic Initiative.

fairSTREAM

Objectives

The main aim of the Strategic Initiative fairSTREAM is to develop and demonstrate a co-production methodology for including equity and justice (fairness) alongside efficiency in developing sustainable policy options across the food-water-biodiversity nexus. The specific objectives are first, to take stock of and expand on IIASA co-production methods to account for ***procedural and outcome fairness*** in policy scenarios and deliberations. Second, to design and test a systems-informed ***stakeholder knowledge co-production*** process in the Bhima basin with the purpose of developing fair and sustainable policy options for the food-water-biodiversity nexus. Third, to

incorporate biodiversity qualitatively and quantitatively in the food-water-land debate. And fourth, to translate and quantify co-produced narratives to build large-scale ***quantitative simulations*** based on a ***coupled agent-based human adaptation model, a hydrological model, and biodiversity model,*** to in turn inform co-production processes.

The fairSTREAM SI has been progressing well in advancing IIASA's bottom-up transdisciplinary research in at least four major intersecting dimensions. The SI will be completed by 30 November 2024 (which includes an extension of three months).

Cross-Program Collaborations

FairSTREAM spans three research groups across two IIASA programs but also has synergies with all other SI projects. Some examples of these synergies are: a) cooperation with the JustTrans4All project on the "Justice considerations in climate research", resulting in a publication in Nature Sustainability (Zimm et al., 2024); b) provision of a case study for the TRUST SI; and c) collaboration with the RESIST SI on the modelling approaches that were adopted. FairSTREAM also engaged with the IIASA community through surveys and bilateral interactions on transdisciplinary research, which will be expanded during the last year of the project. In the fall of 2023, they co-organized a Justice Framework Workshop at IIASA, together with the EQU Program and other SI projects. Together with the TRUST project, the project plans a IIASA transdisciplinarity workshop in October 2024.

FairSTREAM, has been regularly present at key IIASA events:

• Poster at IIASA-OeAW: A poster titled 'Transdisciplinarity in practice: the food-water-biodiversity nexus and its fairness in the Upper Bhima Basin' was presented at the Systems Analysis for Reducing Footprints and Enhancing Resilience Conference (17th November, Vienna) on the fairSTREAM project approach and its expected outcomes. https://iiasa.ac.at/events/iiasa50/austria
• Presentation by Barbara Willaarts et al at IIASA-OeAW: "From Nexus theory to practice: Experiences from co-production processes," presented at the session "Sustainable Management of Water-Energy-Food- Land-Ecosystem Nexus" on November 17th, 2022, at Systems Analysis for Reducing Footprints and Enhancing Resilience Conference https://iiasa.ac.at/events/iiasa50/austria
• Presentation at EGU 2023 by Jens de Bruijn: GEB: A large-scale agent-based socio-hydrological model – simulating 10 million individual farming households in a fully distributed hydrological model
• Hanger-Kopp et al.: Transdisciplinary design and qualitative systems tools as foundations of nexus research. TIFAC-IIASA international conference, 11 August 2022.
• Hanger-Kopp et al.: Using systems thinking for knowledge co-production: beyond participatory system dynamics approaches. IIASA 50th Anniversary Conference, Seoul 12 October 2022.
• fairSTREAM-TIFAC expert workshop on February 11, 2022, with presentations by Jens de Bruijn, Juliette Martin, Prof. Suntil Nautiyal (Institute for Social and Economic Change, Bengaluru) and Prof. KS Rao (Delhi University).
• Physical workshop at IIASA led by Prof. Woo-Kyun Lee and 14 other researchers from Korea University on May 24, 2022

Results

Centering justice in knowledge co-production

Conceptually, fairSTREAM contributes to the development and mainstreaming of transdisciplinary research and knowledge co-production methods at IIASA, with the specific objective, to highlight justice implications as well as the system's analytical potential of co-production methods.

This involved a IIASA-wide survey and focus groups on transdisciplinary issues at the outset of the project. Expert interviews with self-reported experts on transdisciplinarity, then provided a data set to explore good practices in designing transdisciplinary research projects (Irshaid et al, under revision for the journal Sustainability Science).

As part of its mainstreaming efforts, fairSTREAM also took an inventory of co-production methods in use at IIASA, and integrated them in the fairSTREAM toolkit, which is available online at https://iiasa.ac.at/models-tools-data/fairstream-toolkit. The associated working paper highlights how co-production methods can contribute to procedural justice and analyze distributive justice issues, as well as their capacity to enhance systems thinking. This document is being further developed throughout the project and serves as a baseline for a publication on centering justice in co-production (led by Susanne Hanger-Kopp and Adam French), to be submitted to PLOS One, as well as the methods applied in fairSTREAM case study in the Bhima basin (see below). fairSTREAM particularly develops insights on procedural justice, which are crucially linked to knowledge co-production as a normative concept. This work also contributed substantially to the respective section of the IIASA/EQU Justice Framework (Hanger-Kopp et al. 2024).

fairSTREAM continuously fosters discussion on transdisciplinary research and knowledge co-production at IIASA, providing food for thought through the IIASA Blog, participating in IIASA connect events, and contributing to workshops. This summer, fairSTREAM researchers will contribute the module on transdisciplinary research to the IIASA Systems Analysis Summer School, and together with the TRUST SI hosts a workshop to develop terms of reference for transdisciplinary research at IIASA.

Publications

The published papers resulting from the fairSTREAM project are De Bruijn et al (2023), Johannesson et al (2022), Kanade et al (2023) and Zimm et al (2024). Other publications are listed below, followed by a list of participation in global activities, lectures, courses, and other capacity building efforts.

- Hanger-Kopp, S. (May 2023). Stakeholder engagement, co-production, and transdisciplinary research. I*IASA Blog*. Retrieved March 22, 2024, from https://iiasa.ac.at/blog/may-2023/stakeholder-engagement-co-production-and-transdisciplinary-research
- Hanger-Kopp. S. participated in the IIASA Connect Coffee Talk on Equitable research partnerships. (March 2023).
- Hanger-Kopp, S. hosted an interactive session on transdisciplinary research. At the TRUST workshop TRUST SI Workshop: Empower, Engage, Trust - Building Bridges between Science and Society (1 December 2023)
- Hanger-Kopp, S., Kikstra, J. S., Mintz-Woo, K., Scheifinger, K., Schinko, T., Wong, C., Woodhouse, E., & Zimm, C. (2024). IIASA/EQU Justice Framework: A descriptive guideline for science and policy (IIASA Working Paper) [Working Paper].

Systems Science Methods: Coupled agent-based human adaptation model, a hydrological model, and biodiversity model

Over the course of the project, the Geographical, Environmental, and Behavioral (GEB)-model (https://github.com/GEB-model) has been developed collaboratively by the three IIASA research groups involved (Water Security or WAT; Biodiversity, Ecology, and Conservation or BEC; Equity and Justice or EQU), and The Institute for Environmental Studies in the Netherlands (VU-IVM). This new agent-based model (ABM) simulates the behavior of 10 million individual farm households with a heavily adjusted hydrological model (CWatM), which were then integrated in a joint effort. GEB is the first model that can simulate the interactions of the water cycle, individual households (i.e., farmers) and changes in biodiversity (i.e., forests) at a hyper-resolution (30 arcseconds with a field-scale sub-grid) with a daily timestep in major hydrological basins.

Farmers exhibit autonomous heterogeneous behavior based on their assets, the environment (e.g., water availability), management policies, and social network. All decisions taken by the agents influence the hydrological model, which creates bi-directional feedback loops. This work has been published in Geoscientific Model Development, an EGU Copernicus journal (de Bruijn et al., 2023).
As part of this model, the GEB/CWatM was coupled with the PlantFATE model (https://github.com/jaideep777/Plant-FATE), which allowed bi-directional interactions between water and biodiversity to be simulated. This technically challenging effort establishes crucial groundwork for a long-term collaboration between WAT and BEC, as further research, such as in the RESIST project can now benefit from this model. Elisa Stefaniak from the Biodiversity, Ecology, and Conservation Research Group leads a publication on this coupling.
During the second NMO/RMO workshop (see Table 1), preliminary model results from the three coupled models were presented. Several storylines were then integrated into the models and presented in the third NMO/RMO workshop (see Table 1). This continues to be the focus for the remainder of the project (alongside the production of relevant publications).

- De Bruijn, Smilovic M, et al. GEB-model open-source repository in collaboration with IVM-VU (The Netherlands) https://github.com/GEB-model
- Joshi J., Stefaniak E, et al. PlantFATE open-source repository https://github.com/jaideep777/Plant-FATE

Integrating methods at the food-water-biodiversity nexus

We integrate a conceptual work, practical experience in knowledge co-production and the coupled models to gain empirical insight into development opportunities at the food-water-biodiversity nexus in the Upper Bhima basin, in India. We first designed the applied research case in the Bhima basin with our team in India lead by the Society for Promoting Participative Ecosystem Management (SOPPECOM) and supported by the Indian Institute of Science Education and Research (IISER). Our team there, then started a variety of outreach activities to local stakeholders, policy makers, and journalists, by means of informal conversations, focus groups, and surveys. At the heart of effort have been two stakeholder workshops in Pune with stakeholders from the region, ranging from farmers to policy makers and scientists. For both workshops, IIASA scientific staff traveled to Pune (India) to engage in the workshop. The first workshop (~60 attendees) focused on understanding the situation and issues in the food-water-biodiversity nexus in the Bhima basin, which included a participatory mapping exercise and the development of participatory causal loop diagrams.

This effort led to the publication of the "Situational Analysis of the Upper Bhima sub-basin in the context of the Water-Food-Biodiversity Nexus" (Kanade et al., 2023) in both English and Marathi. In the second workshop (~30 attendees), the model results were presented and solutions were elicited for the issues identified in the first workshop and summarized in the situational report. The third and final workshop is planned for November 2024, where we will present jointly developed narratives on just and sustainable development at the FWB nexus and associated modelling results.

This engagement work has been accompanied by a dedicated review effort on the FWB nexus in India (Martin et al. being revised for Environmental Science and Policy). Moreover, our team member Radhika Kanade is preparing a publication building on results from a fairSTREAM survey, focused on perceptions of biodiversity.

Moreover, we will present intermediate results of this integrated work at the Sustainability Research and Innovation Congress in June in Helsinki. An integrated publication is in preparation by Jens de Bruijn on the implications of equitable water distribution in the food-water-biodiversity nexus.

Other activities include:

- Willaarts, B et al. will convene a session at the Sustainability Research and Innovation Conference 2024 "Moving beyond scientific excellence: Mainstreaming transdisciplinary

approaches in climate and WEFE nexus policy and practice for wider societal impacts" and presenting part of the co-production processes developed in fairSTREAM.
- KJ Joy. "Rivers as Spaces of Contestations: Citizen Science, Activist Research & Co-Production of Knowledge" as part of the Moving Rivers Webinar Series, hosted by the Wageningen University, The Netherlands.

JustTrans4ALL

Objectives
The project objective is to develop, quantify and test the first set of just transition scenarios towards a net-zero carbon society. To this end, the project is well on track and has reached the planned milestones: of a) identifying elements for a just transition, b) developing and c) testing the framework, d) expanding and measuring multidimensional poverty concepts, and e) developing and f) testing the scenarios.

Cross-Program Collaborations
Several research ideas have emerged from this fruitful cross-program collaboration, e.g., to use the framework for a more systematic expert elicitation on the perceived fairness of patterns in scenarios to enhance the narrative and scenario space but also to improve on participatory justice. Several projects provide opportunities for synergies and continuation of this work (e.g., GENIE, ELEVATE and UPTAKE, the Justice Model Intercomparison Project (JUSTMIP) through ECE; Rainforest, FireLog in EQU-POPJUS). Similarly, the empirical data are relevant for various projects on decent living standards, health, climate, and wellbeing (i.e., the EDITS network work on wellbeing indicators, DLS-DLE advancement, and global scientific initiatives such as the Earth Commission). In collaboration with the IIASA EQU research group, fairSTREAM and TRUST, a Justice Framework Workshop at IIASA was organized for NMOs/RMO representatives and IIASA staff.

Results
The main highlight of JustTrans4ALL is Zimm, Mintz-Woo et al. (2024). The conceptual framework contributes to a holistic and multidimensional understanding of climate justice. It is rooted in philosophical theory and synthesizes justice considerations for scientists and policymakers. It aims to enhance interdisciplinary understanding of justice to prevent mischaracterization and misuse for climate action delay and argues that more justice-related research is essential in the next IPCC cycle, including a Justice Model Intercomparison Project for mitigation scenarios. Other results are presented in the following sections, by category.

Systems Science Methods: Soft Systems meets Prospective Analysis
JustTrans4ALL aim is to develop, quantify and test the first comprehensive set of just transition scenarios towards a net-zero carbon society. The project connects a soft-systems analysis approach, grounded in ethical reasoning (for conceptualizing a comprehensive net-zero just transition framework), with quantitative empirical methodologies and insights (for retrospectively assessing specific dimensions of justice), and prospective model-based analysis (for a forward-looking assessment), where human wellbeing is at the center. This novel approach promotes and supports interdisciplinary work that is cognizant of real-world challenges and debates. A thorough understanding of and grounding in ethics and justice related to IIASA´s research outputs is a crucial advancement and scientific obligation given IIASA's global leadership and credibility.

Publications
The papers that have been published include Belmin et al (2022), Belmin et al (2022), Brutschin and Andrijevic (2022), Min and Rao (2023), Pachauri et al (2022, 2023), and Zimm et al (2022), (2024), Fu and Zimm (2024). A list of participation in global activities, lectures, courses, and other capacity building efforts are listed below.

NMO/RMO engagement: Participation in global activities, lectures, courses, other capacity building efforts

An NMO Kick-off workshop was held in December 2021 to collect inputs from different countries, which also included a survey. Two NMOs (Korea and China) have funded country specific spin-offs at national and sectorial scale with ongoing research exchanges. With regards to capacity development and early career researcher development, the team has hosted two interns and several YSSPs. They have conducted a university lecture series on just transitions (Vienna University of Applied Art), a summer course (European Forum Alpbach) and several lectures at local universities. The team will also host a workshop on 'Justice and Modelling advances' at the IIASA summer school in July 2024. Further, the project team have given lectures at local schools and associations (e.g., Rotary Club, Club Alpbach), and have collaborated with artists and climate activists (Fridays for Future, Klimacamp, Science Meets Arts, Theatre of the Oppressed) in workshops on climate justice.

Policy Advice/Advisory Bodies

A "Justice framework to guide climate research and policy discussions" (Zimm et al., 2024) was published. Together with other published forthcoming products, these insights aim to inform the next cycle of the IPCC scenario generation and related climate policy discussions with the team participating in events at SBSTA and COP (details below).

Ongoing advisory activities:

- Project team members have been contributing to the ongoing Second Austrian Assessment Report on Climate Change (to be published in 2025)
- Kian Mintz-Woo has been invited to contribute to the Irish government's Environmental Protection Agency's Carbon Budgets Working Group to bring a perspective on climate justice and just transitions (January 2023)
- Jarmo Kikstra, Setu Pelz, and Shonali Pachauri wrote a UN DESA Science-Policy Brief on "Eliminating multidimensional poverty by providing decent living standards for all" for the Multistakeholder Forum on Science, Technology and Innovation for the SDGs (2022)
- Caroline Zimm has been invited to the advisory board of the Lower Austria Climate Alliance (September 2023)
- Caroline Zimm served on the review panel for the FORMAS call "A sustainable transformation for climate action in a changing world" (July 2023-September 2023)

News, Magazines, Blogs & Podcasts

- Jarmo Kikstra gave podcast interview to radio show Planet Philadelphia, on "Making climate crisis transition equitably" 10.11.2021, Philadelphia, USA (virtual, Zoom)
- Options Winter 2021 contribution on JustTrans4ALL.
- Caroline Zimm gave an interview to Period Magazine on Energy Poverty and Justice, 3 June 2022
- IIASA Nexus Blog on Climate Justice Beyond Carbon Equity.

Conferences and meetings

JustTrans4ALL presented the interdisciplinary project insights at more than 55 international or local conferences and meetings of different disciplines, such as climate and geoscience, philosophy, sustainability and environmental change, integrated assessment modeling, scenario research, (ecological) economics and development. Many of these took place in NMO countries, i.e., Austria (12), United Kingdom (7), United States (4), and Korea (3). Project team members were invited speakers at several of these events. Many events involved policymakers, such as SEforALL, UN Population Export Group meeting, SBSTA Bonn, COP, Just Transitions expert groups and local Austrian stakeholders. A detailed list is available upon request.

RESIST

Objectives
The goal of this SI is to develop a modeling framework that integrates biophysical feedback and socio-economic drivers affecting the Resilience of Ecosystem Services provided by Intact and Sustainably managed Terrestrial ecosystems (RESIST). To account for scientific and socio-economic perspectives on sustainable ecosystem management, the project aims to address complex science-policy questions while engaging in an active stakeholder dialogue to identify strategies for the sustainable management of natural resources in each study region.

Cross-Program Collaborations
Taking advantage of the multidisciplinary diversity and fostering cross-collaboration among IIASA staff researchers the project has been designed in close collaboration with other Strategic Initiatives (led by researchers working in the WAT and EQU groups). Therefore, and due to the envisaged coupling of the PlantFATE and CWatM models, this has led to a strong collaboration between staff members working in different research groups. Based on the application of models developed by respective research group (i.e., PlantFATE and CWatM), three cross-collaborative IIASA research proposals have been submitted in 2023/2024 (one with BEC, EF, one with BEC, WAT, and one with BEC, EF, EQU and EM research groups).

Results
The most important highlight of RESIST is having inaugurated this SI project during the 60th anniversary of the Association for Tropical Biology and Conservation (ATBC) for which the Principal Investigator Florian Hofhansl received special attention in a session with big attendance at the society's 58th conference entitled "Conserving Tropical Biodiversity and Achieving Socio-Ecological Resilience in the Anthropocene: Opportunities and Challenges". The project took the opportunity to report on this achievement by publishing an IIASA nexus blog: https://iiasa.ac.at/blog/sep-2022/achieving-socio-ecological-resilience-in-anthropocene-opportunities-and-challenges

Systems Science Methods: Soft Systems meets Prospective Analysis
RESISTS will advance systems analysis by applying a multidisciplinary framework that allows to quantitatively address pressing but currently intractable science-policy questions: (1) What is the role of plant functional diversity and adaptive capacity for ecosystem resilience to climate change? (2) How will natural and managed ecosystems respond to future changes in climate, such as droughts? (3) What is the effect of biodiversity-ecosystem functioning feedback on regional precipitation patterns, thus affecting the availability of natural goods from agricultural production systems?

Publications
The articles published by RESIST are Franklin et al. (2023), Joshi et al. (2022), Joshi et al. (2023), and Rius et al. 2023).

NMO/RMO engagement: Participation in global activities, lectures, courses, other capacity building efforts
RESIST has set up strong collaborations with IIASA NMOs/RMO, which allowed the researchers to obtain project specific data for model calibration from local experts working in the study regions. Ongoing research activities shared with the proposed collaboration partners are listed below by respective country:

- For Brazil: The project has completed model calibration for the Amazon FACE study site, which has resulted in one published article (Rius et al., 2023).
- For India: (i) the project assisted the NMO partner Dr. Rajiv Chaturvedi, BITS Goa, in setting up a site for data collection and monitoring of forests in the Netravali Wildlife Sanctuary in Goa, India. Dr. Rajiv has already shared preliminary data from the forest

census, such as forest structure and plant functional traits, as well as plant phenology (PhenoCAM scans) and forest structure (TLS LiDAR scans). Data collection is still ongoing and upcoming data will be continuously shared among RESIST research partners for which we have identified specific research objectives and corresponding data requirements in consultation with Indian NMO partners; (i) Dr. Deepak Barua from IISER Pune, India; (ii) Dr. Rajiv's PhD student Karun Jose, whom has applied for YSSP 2024, and (iii) Shipra Singh (current IIASA postdoc) whom conducted a field campaign in the Himalaya region for acquiring data on stakeholder preferences and ecosystem services.

- For Israel: The project met with Prof. Tamir Klein to discuss specific project objectives and data requirements. However, due to the ongoing situation in Israel, these activities have been postponed due to the currently ongoing crisis.

- For China: The National Natural Science Foundation of China (NSFC) indicated a strong interest for potential co-funding via a grant provided to Chinese researchers (cf NSFC-IIASA call 2024), which resulted in several project proposals (listed below). However, only the one submitted by Jinfeng CHANG (a guest researcher in IBF) has been granted funding of the Chinese partner:

    - Jinfeng CHANG: Food security (Petr HAVLIK, IBF)
    - Ping HAN: Mangrove C storage (RESIST, WAT)
    - Qingxu HUANG: Biodiversity conservation pathways in Global South (Brian FATH, ASA)
    - Mingkai JINAG: Biodiversity and ES of tropical forests (RESIST, BEC)
    - Gengyuan LIU: Ecosystem stability and resilience in China/Brazil (Ali KHARRAZI SYRR)

Conference/talks/capacity building/ public engagement

- Stefaniak, E., Tissue, D., Dewar, R., Hofhansl, F., Joshi, J. & Medlyn, B. (2023). Optimality Theory informed Carbon Storage Allocation under drought. In: 2nd Workshop Carbon Allocation in Plants - Advances in carbon allocation and acquisition, 20-21 November 2023, Versailles, France
- Joshi, J., Hofhansl, F., Singh, S., Stocker, B., Vignal, T., Brännström, Å., Franklin, O., Blanco, C., Aleixo, I., Lapola, D. et al. (2023). Predicting the adaptive responses of biodiverse plant communities using functional trait evolution. In: Ecological Society of American 2023 Annual Meeting, 6-11 August 2023, Portland, OR, USA
- Lichstein, J.W., Longo, M., Bereswill, S., Blanco, C.C., Bonal, D., Chave, J., Christoffersen, B.O'D, de Paula, M.D., Derroire, G., Fisher, R.A. et al. (2023). A model intercomparison project to study the role of plant functional diversity in the response of tropical forests to drought. In: Ecological Society of American 2023 Annual Meeting, 6-11 August 2023, Portland, OR, USA
- Joshi, J., Hofhansl, F., Singh, S., Stocker, B., Brännström, Å., Vignal, T., Casagrande Blanco, C., Aleixo, I., Lapola, D., Prentice, I.C. et al. (2023). Roles of diversity and adaptation in the eco-evolutionary responses of biodiverse plant communities to climate change. In: EGU General Assembly 2023, 23-28 April 2023, Vienna, Austria
- Hofhansl, F., Barrantes, O.V., Chacón-Madrigal, E., Hietz, P., Weissenhofer, A., Prommer, J., Wanek, W. & Fuchslueger, L. (2023). Do fine root morphological and functional adaptations support regrowth success in a tropical forest restoration experiment? In: EGU General Assembly 2023, 23-28 April 2023, Vienna, Austria
- Hofhansl, F. (2022). Biodiversity controls ecosystem functioning and associated services in a geomorphologic heterogeneous tropical forest in southwestern Costa Rica. In: 58th annual conference meeting of the Association for Tropical Biology and Conservation (ATBC 2022), 10-14 July 2022, Cartagena, Colombia.

- Franklin, O., Fransson, P., Hofhansl, F. & Joshi, J. (2022). Plants maximize the conductive efficiency of the xylem. In: EGU General Assembly 2022, 23-27 May 2022, Vienna, Austria

News / Blog articles (related to the work conducted in the RESIST SI-project)

- Blog posting about inauguration of fairSTREAM/RESIST projects held at the Association for Tropical Biology and Conservation (https://iiasa.ac.at/blog/sep-2022/achieving-socio-ecological-resilience-in-anthropocene-opportunities-and-challenges)
- Blog posting about publishing the PlantFATE model (https://iiasa.ac.at/blog/nov-2022/how-do-droughts-affect-ability-of-trees-to-absorb-co2)
- Blog posting about upcoming project fusing ground observations, remote sensing and modeling of vegetation dynamics in the Austrian rainforest, Costa Rica (https://iiasa.ac.at/blog/feb-2024/rainforest-gets-digital-twin)
- Blog posting about coupling of PlantFATE and CWatM models (in development by Elisa STEFANIAK)

Stakeholder engagement (with NMO collaboration partners)

- Shipra Singh has conducted a local field campaign in the Himalaya region in India to acquire data on stakeholder preferences and stakeholder perspectives on biodiversity, and ecosystem services provided by local forest ecosystems.
- In addition, the project has been working closely with the FairSTREAM project to achieve similar goals in the Bhiman basin, India.

TRUST

Objectives
The aim of the TRUST SI is to: (i) strengthen the knowledge base for raising awareness on fostering trust through participation-driven science, (ii) lower the barrier for scientists to use participation-driven approaches, and (iii) provide concrete empirical evidence of the role of participation driven science for raising trust in science.
The TRUST SI has been steadily advancing IIASA participatory research and raising awareness about fostering trust through participation-driven science, despite facing challenges such as a smaller-than-anticipated total budget and delays stemming from an extended period of staff sick leave. Nonetheless, the project remains confident in their ability to achieve the goals and objectives within the prolonged three-year timeline, with the project ending 31 October 2025.

Cross-Program Collaborations
Researchers from IIASA's Advancing Systems Analysis (ASA) Program, Biodiversity and Natural Resources (BNR) Program, Energy, Climate, and Environment (ECE) Program as well as from the Population and Just Societies (POPJUS) Program are joining forces to carry out the IIASA TRUST Strategic Initiative.

Results
The most important highlights of the TRUST project have revolved around policy impact, notably:

- A 1.5-day workshop at IIASA, connecting over 30 researchers affiliated with IIASA and the broader research community in a peer-to-peer learning event. Participants gained insights and connected on diverse participatory research approaches employed at IIASA, spanning from participatory data collection and analysis to modeling and decision-making techniques. A standout feature of the workshop was its dedication to exploring how participatory research approaches could cultivate and strengthen trust, serving as a crucial way of elevating the profile of participatory research approaches in fostering trust

within IIASA. As the first of its kind at IIASA (in several years), the event received overwhelmingly positive feedback and connected a new generation of forward and outward looking researchers aiming to deliver on IIASA's objectives.
- In addition, TRUST has had several meetings with policy-makers, most notably with the Austrian Federal Minister for Education, Science, and Research to discuss the TRUST initiative (more info here) and with the senior leadership of the Austrian Academy of Sciences.

Systems Science Methods: Participation-driven science

TRUST focuses on: (i) strengthening the knowledge base for raising awareness on fostering trust through participation-driven science, (ii) lowering the barrier for scientists to use participation-driven approaches with an open-access toolkit and Community of Practice (CoP), and (iii) providing concrete empirical evidence of the role of participation driven science for raising trust in science.

Publications

All publications are currently in preparation. Below is a list of participation in global activities, lectures, courses, and other capacity building efforts.

NMO/RMO engagement: Participation in global activities, lectures, courses, other capacity building efforts

Engagement with IIASA NMOs has taken place through two primary channels: i) directly via NMO routes, and ii) indirectly within IIASA NMO countries.

Engagement via NMO routes

- Austria: Policy exchange with the Austrian Academy of Sciences. Met with senior leadership of the Austrian Academy of Sciences, the leading Austrian non-university institution for science and research, to discuss the need for raising levels of trust in science among the Austrian and European public.
- China: Participated in the IIASA National Natural Science Foundation of China (NSFC) Call
- Finland: Policy exchange with the Finnish Environment Institute (SYKE)
- Israel: Policy exchange and collaboration with researcher from the Hebrew University of Jerusalem recommended by the Israel Committee for IIASA
- Korea: Policy exchange with the National Research Foundation of Korea (NRF)

Engagement within IIASA NMO countries

- Austria: Met with the Austrian Federal Minister for Education, Science, and Research to discuss the institute's commitment to participation-driven science and the TRUST initiative, which focuses on strengthening the knowledge base for raising awareness on fostering trust through participation-driven science, lowering the barrier for scientists to use participation-driven approaches, and providing concrete empirical evidence of the role of participation driven science for raising trust in science. More info here.
- Germany: Collaboration with researchers from the Communicating Scientists: Challenges, Competencies, Contexts (fourC) Research Group at TU Braunschweig & Potsdam Institute for Climate Impact Research (PIK)
- Kenya: Collaboration with researcher from Under the Microscope (UTM), a non-profit organization advancing science and innovation in Africa
- India: Collaboration with researchers from IISER Pune and SOPPECOM via the IIASA fairSTREAM SI

- USA: Collaboration with researchers from the Urban Institute and RAND Corporation as well as Princeton University

Participation in policy networks

- UN-DataForum session co-organized with UNDPOGC and partners: "Building evidence to rebuild trust in governance systems"
- Remote participation in the OECD meeting "Tackling disinformation: Strengthening democracy through information integrity"
- Engaged with the OECD Global Science Forum (GSF) on harnessing participatory research activities for fostering trust in science
- Participated in the 2022 GOVTRUST Summer School: A Multi-Level Perspective on Trust and Public Governance for Societal Transitions

Conferences attended

- 6th European Climate Change Adaptation Conference 2023: TRUST SI leads a session on trust in climate science as a driver towards a climate-resilient future and the role of engagement strategies.
    - Impact: Introduced TRUST SI to a diverse audience of 25+ climate researchers from Europe, fostering connections and paving the way for potential survey applications
- Connect.Collaborate.Create - Bridging Communities for Participatory Research and Citizen Science Conference 2023: TRUST SI leads a session on establishing trust and applying tools for community engaged research, policy, and practice
    - Impact: Introduced TRUST SI to a diverse audience of 25+ citizen and participatory science researchers from Europe and the United States, fostering connections with three Horizon Europe projects on trust in science (IANUS, VERITY and POIESIS), as well as with collaborators from the Centre for Social Innovation (ZSI) and the Urban Institute, amplifying potential collaborations and knowledge exchange.

Surveys sent

- Sent and received initial responses to the TRUST survey (developed with the Communicating Scientists: Challenges, Competencies, Context (fourC) of Technical University Braunschweig) from the Donate Water and FairSTREAM projects, with additional responses anticipated after the climate science crisis simulation conducted with the Centre for Systems Solutions (CRS) at IIASA in February 2024. Throughout the remainder of 2024, the project's focus lies on expanding project networks and pinpointing new opportunities for survey application.

Reviewing initial results from survey on scientists perceived efficacy fostering trust in science using participatory methods. Survey has gone through two rounds of critical reviews from the Behavioral Science for Policy Lab (BSPL) at Princeton, as well as the Communicating Scientists: Challenges, Competencies, Context (fourC) research group at TU Braunschweig.

7.2. Program budget and staff

The 2021-2024 budget of the Strategic Initiatives is shown in Table 7-3. The total sum for 2024 does not yet include the deduction of two newly awarded Strategic Initiatives, to be announced to the Council meeting in mid-June 2024.

Table 7-3 Strategic Initiatives Program budget 2021-2025

	2021 ACTUAL	2022 ACTUAL	2023 ACTUAL	2024 FORECAST	2025 FORECAST
SI direct expenses (staff and non-staff)	€ 112,597	€ 113,386	€ 85,560	€ 82,700	€ 82,740
Project Share 2021 **FairSTREAM**	€ 13,525	€ 112,510	€ 166,224	€ 107,004	€ -
Project Share 2021 **JustTrans4All**	€ 1,093	€ 88,851	€ 163,683	€ 142,874	€ -
Project Share 2022 **TRUST**	€ -	€ 25,479	€ 106,520	€ 127,774	€ 99.695
Project Share 2022 **RESIST**	€ -	€ -	€ 89,140	€ 170,859	€ 100,000
Balance	€ 689,444	€ 412,773	€ 140,034	€ 114,629	€ 463,405

The Full Time Equivalent (FTE) and classification of the SI Program staff throughout the years 2021-2024 is shown in Table 7-4. The nationalities of the staff are from Austria, Germany, and Mexico.

Table 7-4 Strategic Initiatives Program staff FTE and classification

	2021	2022	2023	2024
Employee 1, R-4	0.50	0.50	0.25	0.30
Employee 2, O-5	0.60	0.60	0.70	0.00
Employee 3, R-2	0.50	0.50	0.50	0.60
FTE Total	1.60	1.60	1.70	0.90

7.3. SWOT analysis

Strengths (internal)	Challenges (internal)
Yearly internal calls give flexibility to react and adapt quickly to a constantly changing world Cross-program collaboration enables exploitation of the synergies of individual program strengths in focused project-level activities, representing a unique opportunity for cross-program collaboration on new topics Opportunity for young, up and coming researchers and women in particular at IIASA to gain project coordination and project management experience, take on added responsibilities and progress through the IIASA career ranks. In that way their CV improves and potentially helps to attract further funding. Ideal testing ground for blue skies thinking, with ample flexibility that is not usually available with external project funding. This is especially the case as early-career researchers are driving these SI projects and are being given the opportunity to work on their project ideas Unique opportunity with great visibility within and outside IIASA to work with colleagues from different programs and disciplines Engages with the National Member Organizations of IIASA and provides opportunities to link to researchers within NMO countries.	The Strategic Initiatives was created with too many objectives in mind (See first section). Some of these objectives are tradeoffs. Projects are short term while complex topics and interdisciplinarity require longer term collaborations to mature into robust solutions or outputs. Coordination between programs is hard to achieve, especially when the culture and the administrative structures are not well designed for such collaborations Different expectations by NMOs on what SI should do and to what degree NMOs should we involved in the initial setup of the proposal. NMOs/RMO engage with diverse intensities and motivations, which makes the collaboration challenging, and hence the interests of some more active NMOs/RMO might be more reflected than those of less active members. Until now it has been hard to fully engage with institutions within the NMO countries. Co-funding by NMOs has until now been quite limited since funding cycles are not aligned with the current SI process. There is a current mismatch between the duration of the SI Program cycles (call for proposals start in September of one year, and ends in June of the next year) and the funding cycles of the NMOs/RMO (start and end dates vary by country and may not align to start of a Strategic Initiative).
Opportunities (external	Threats (external)
Complex problems require transdisciplinary and interdisciplinary approaches, and collaboration between multiple actors, to find complex solutions so the SI program is positioned in an ideal way to achieve this Benefits to early career researchers could be further amplified by providing more detailed feedback to the applicants. The SI process could potentially be redesigned to more closely align with NMOs interest and the NMOs funding cycle. There is big potential in co-designing the projects together with NMOs and to explore funding at the initial stage. This is in particular interesting for projects which concern several NMOs which face similar (e.g. regional) challenges.	Projects are thought of as seed funding, which cannot otherwise be funded externally. The funding is usually focused and once a project has been funded there is little scope for extension/co-funding and additional work. The projects will not develop to sufficient maturity to attract further funding and might therefore not be able to continue even though being innovative. Talented young researchers might get better offers outside IIASA. Outreach may require additional resources that go beyond the project resources.

References

Belmin, C., Hoffmann, R., Elkasabi, M., & Pichler, P.-P. (2022). LivWell: A sub-national Dataset on the Living Conditions of Women and their Well-being for 52 Countries. *Scientific Data*, *9*(1), 719. https://doi.org/10.1038/s41597-022-01824-2

Belmin, C., Hoffmann, R., Pichler, P.-P., & Weisz, H. (2022). Fertility transition powered by women's access to electricity and modern cooking fuels. *Nature Sustainability*, *5*(3), 245–253. https://doi.org/10.1038/s41893-021-00830-3

Brutschin, E., & Andrijevic, M. (2022). Why Ambitious and Just Climate Mitigation Needs Political Science. *Politics and Governance*, *10*(3), 167–170. https://doi.org/10.17645/pag.v10i3.6156

de Bruijn, J. A., Smilovic, M., Burek, P., Guillaumot, L., Wada, Y., & Aerts, J. C. J. H. (2023). GEB v0.1: A large-scale agent-based socio-hydrological model – simulating 10 million individual farming households in a fully distributed hydrological model. *Geoscientific Model Development*, *16*(9), 2437–2454. https://doi.org/10.5194/gmd-16-2437-2023

Franklin, O., Fransson, P., Hofhansl, F., Jansen, S., & Joshi, J. (2023). Optimal balancing of xylem efficiency and safety explains plant vulnerability to drought. *Ecology Letters*, *26*(9), 1485–1496. https://doi.org/10.1111/ele.14270

Fu, X., & Zimm, C. (2024). Towards a decent transport for all: The transport dimension of decent living standards for just transitions to net-zero carbon emission. *Multimodal Transportation*, *3*(2), 100136. https://doi.org/10.1016/j.multra.2024.100136

Johannesson, P., Zhemchugova, H., & Hanger-Kopp, S. (2022). An Ontological Analysis of Justice. *Proceedings of the 16th International Workshop on Value Modelling and Business Ontologies (VMBO 2022), Held in Conjunction with the 34th International Conference on Advanced Information Systems Engineering (CAiSE 2022)*, 10. https://pure.iiasa.ac.at/id/eprint/18070/

Joshi, J., Hofhansl, F., Singh, S., Stocker, B. D., Brännström, Å., Franklin, O., Blanco, C. C., Aleixo, I. F., Lapola, D., Prentice, I. C., & Dieckmann, U. (2023). *Competition for light can drive adverse species-composition shifts in the Amazon Forest under elevated CO2* (p. 2023.07.03.547575). bioRxiv. https://doi.org/10.1101/2023.07.03.547575

Joshi, J., Stocker, B. D., Hofhansl, F., Zhou, S., Dieckmann, U., & Prentice, I. C. (2022). Towards a unified theory of plant photosynthesis and hydraulics. *Nature Plants*, *8*(11), 1304–1316. https://doi.org/10.1038/s41477-022-01244-5

Kanade, R., Lohakare, K., Bhadbhade, N., Joy, K. J., Thomas, Bejoy. K., Martin, J., & Willaarts, B. A. (2023). *Situational Analysis of the Upper Bhima sub-basin in the context of the Water-Food-Biodiversity Nexus*. Zenodo. https://doi.org/10.5281/zenodo.8255959

Min, J., & Rao, N. D. (2023). Growth and inequality trade-offs to eradicate absolute poverty. *Heliyon*, *9*(11), e21441. https://doi.org/10.1016/j.heliyon.2023.e21441

Pachauri, S., Pelz, S., Bertram, C., Kreibiehl, S., Rao, N. D., Sokona, Y., & Riahi, K. (2022). Fairness considerations in global mitigation investments. *Science (New York, N.Y.)*, *378*(6624), 1057–1059. https://doi.org/10.1126/science.adf0067

Pachauri, S., Pelz, S., Bertram, C., Rao, N. D., & Riahi, K. (2023). Response to comment on "Fairness considerations in global mitigation investments." *Science*, *380*(6646), eadh1463. https://doi.org/10.1126/science.adh1463

Rius, B. F., Filho, J. P. D., Fleischer, K., Hofhansl, F., Blanco, C. C., Rammig, A., Domingues, T. F., & Lapola, D. M. (2023). Higher functional diversity improves modeling of Amazon forest carbon storage. *Ecological Modelling*, *481*, 110323. https://doi.org/10.1016/j.ecolmodel.2023.110323

Zimm, C., Mintz-Woo, K., Brutschin, E., Hanger-Kopp, S., Hoffmann, R., Kikstra, J. S., Kuhn, M., Min, J., Muttarak, R., Pachauri, S., Patange, O., Riahi, K., & Schinko, T. (2024). Justice considerations in climate research. *Nature Climate Change*, *14*(1), 22–30. https://doi.org/10.1038/s41558-023-01869-0

Zimm, C., Schinko, T., & Pachauri, S. (2022). Putting multidimensional inequalities in human wellbeing at the centre of transitions. *The Lancet Planetary Health*, *6*(8), e641–e642. https://doi.org/10.1016/S2542-5196(22)00124-3

8. Capacity Development and Academic Training (CDAT)

8.1. Mission and goals

The mission of CDAT is to educate young and experienced researchers, both within and outside IIASA, to develop capacity in systems analysis, and to sensitize current and future decision makers to systems thinking, applied systems analysis, and the specific tools and methods in which IIASA has prominent expertise.

Pre-2020 IIASA had a very limited educational mission; the reorientation and realignment has been gradual, focusing on quality, and increasing the offer in parallel with how additional resources could be mobilized. The goals for the period 2021-2024 have been described in the IIASA Research Plan 2021-2024.

Many CDAT activities are organized, coordinated, and facilitated centrally across the institute by the CDAT unit (see below), with the intellectual content delivered by IIASA researchers and external collaborators. In addition, many activities (such a mentoring and supervision, trainings on IIASA tools, etc) are naturally and directly organized by the research programs and research groups without the CDAT unit being called upon.

8.2. Main Activities

Following the above mission, the CDAT activities broadly fall into three clusters:

1) **research immersion programs** that allow researchers external to IIASA to spend a limited period of time (1-24 months) in one of the IIASA research groups, to carry out joint research and/or in order to become fluent in one of IIASA's modeling frameworks. This cluster includes the Young Scientists Summer Program and the postdoc programs, but also e.g. the more light-touch opportunity for external faculty to spend their sabbatical at IIASA.
2) **Training and teaching activities**, held either at IIASA or elsewhere; including summer schools, workshops and dedicated trainings on the IIASA modeling frameworks;
3) **Development of internal capacity** for systems analysis, which targets early career researchers (ECRs, here defined as being within 5 years past their highest degree) recruited by the IIASA research programs. Activities under this umbrella aim to generally broaden ERCs perspectives beyond their own field of specialization, to offer new and transferable skill sets, and to grow into new roles.

Ad1: The Young Scientists Summer Program (YSSP)
This IIASA signature program, established in 1977 by the second IIASA director Roger Levien and continuously running since then, has cumulatively hosted more than 2,000 young researchers from more than 50 countries. Every summer around 50 PhD students spend 3 months at IIASA to carry out a research project and to write a report that is the basis for a publishable paper, under the guidance of one or more senior researchers at IIASA. Many past participants have found the program to be transformative for their career and research outlook, and regularly we hear that at least some participants had the time of their life – given the unique combination of focused research, being part of an international and interdisciplinary cohort, and a rich scientific and social program. The YSSP has has also turned out to be a quite effective recruitment tool.

In recent years there have been calls for expanding the program to offer more PhD students the opportunity to participate. We have resisted these calls as we believe the social interaction works better at the current size; however, we now also offer other opportunities for early career researchers to interact with IIASA (summer schools and other training programs), rather than bloating a successful format.

In 2020, during the pandemic, the YSSP was held in virtual format, with half the selected candidates opting to reapply in 2021 and half of them participating via Zoom. In 2021 a larger

than usual cohort was taken into a hybrid version of the program, and only few of them could actually travel to Laxenburg. By 2022 operations had returned pretty much to normal (Chinese participants all had to shift their travel by a few weeks).

Traditionally two awards in the form of a scholarship to return to IIASA for another 3 months have been bestowed for the best YSSP papers, and in 2023 the IIASA Council established a third award, to commemorate the legacy of Roger Levien.

Table 8-1 Number of YSSP by gender and Nationalities 2021-2024

Year	Woman	Man	Total	Nationality
2021	29	30	59	Austria, Belgium, Brazil, Canada, People's Republic of China, Colombia, Finland, France, Germany, India, Italy, Rep. Korea, Mexico, Romania, Russian Federation, South Africa, Sweden, United Kingdom, United States **(19 countries)**
2022	27	22	49	Austria, Brazil, Canada, People's Republic of China, Colombia, France, Germany, India, Indonesia, Israel, Italy, Japan, Rep. Korea, Nepal, South Africa, Sweden, United Kingdom, United States **(18 countries)**
2023	22	28	50	Austria, Brazil, People's Republic of China, Denmark, Finland, France, Germany, Ghana, India, Indonesia, Islamic Republic of Iran, Israel, Italy, Japan, Rep. Korea, Mexico, Nepal, Nigeria, Pakistan, Poland, Spain, United Kingdom, United States **(23 countries)**
2024	27	25	52	Austria, Belgium, Canada, People's Republic of China, Germany, India, Iran, Israel, Italy, Japan, Rep. Korea, Mexico, Netherland, Russia, USA, United Kingdom **(16 countries)**

Ad1: Postdoctoral fellowship programs
IIASA believes that postdocs are the powerhouse of every research organization, especially those individuals that can freely pursue their own ideas and collaborate across IIASA research programs. Hence we internally distinguish postdoctoral fellows, who have formulated their own research proposal and enter through a competitive institute-wide (or wider) process, from postdoctoral researchers who hold a PhD and get hired by one of the research program to contribute to an existing project. Our main focus in CDAT are postdoctoral fellows, as their fellowship terms typically explicitly include a personal training component.

An IIASA-funded postdoc fellowship program was established back in 2006 by then director Leen Hoordijk. The program grew from two 1-year fellowships per year to three to four 2-year fellowships offered in 2017. In 2018 the program was discontinued by the incoming IIASA director, and it has not been revived yet. Since then, the focus has been to attract externally funded postdoctoral fellows, including those that are funded by an NMO/RMO or an organization in their country, as well as so-called Marie Sklodowska-Curie Action (MSCA) postdoc fellows, a highly competitive program funded by the EU.

With some NMOs stepping up, the number of concurrent postdoc fellowship holders at IIASA have remained stable at around 10-12. It is the express goal of the CDAT unit to expand the number of fellowships to 25 by the year 2025. We consider this a critical mass of creative and diverse minds for whom it will be worth for IIASA to also offer additional specific training and

networking opportunities beyond what is already in place for all our early career researchers (see below).

We recently have had encouraging signals from some of our NMOs (incl. Israel, Iran, Korea) to increase their funding commitment for bilateral fellowship programs, and to support the effort reach our goal. We now also have a mechanism in place to increase the number of successful incoming MSCA proposals (3 in 2024 up from 1 per year in the years before; MSCA proposals to IIASA have a success rate that is more than twice as high as the European average – not least because of active support of the applicants by the CDAT unit). At this stage, we are on track towards this goal, assuming that within the next 12 months we are making progress in the negotiations with some specific NMO/RMOs.

Ad 2: Summer schools
Starting in 2024 the CDAT unit has developed and is now hosting an annual 2-week Summer School on Systems Modeling for 30 participants to complement the YSSP with another institute-wide and systems-oriented training opportunity. In 2024 the school was three-fold oversubscribed, which indicates the hunger for more opportunities to get acquainted with systems methodologies.

In addition, CDAT is organizing, with the Water group, a virtual summer school on hydrological modeling. Furthermore, the NODES group is offering a training workshop on advanced topics in geospatial analysis at IIASA, while the SHAW group is continuing to offer an annual training course on demographic modeling in Thailand. CDAT is planning to expand IIASA's summer school program from four in 2024 to at least six courses in 2025, including one on international negotiations.

Ad 2: Other training programs
IIASA has been offering introductory training programs on systems analysis to interested communities, including in NMO/RMO countries. For example, in the context of the 50th anniversary of IIASA in 2022 such programs were held in China as well as in Korea. In addition, in 2023 such a program was also delivered to the International Science Council. IIASA is now in the process of recording a short series of lectures for the purpose of offering them as an online course.

Individual IIASA research programs/groups are offering, regularly or on-demand, training programs on large-scale in-house modeling frameworks. For example, since a few years now, typically at the beginning of every summer the ECE program is holding a MESSAGEix model community training workshop, while the Pollution Management group hosts a biennial GAINS model community meeting in the fall. The GAINS/PM group also been training experts in local pollution control boards in China, India and ASEAN countries.

IIASA has helped to prepare the establishment of the North African Applied Systems Analysis Center (NAASAC) in Cairo, Egypt in 2022, located at the Institute for National Planning. Since then, IIASA through CDAT has also actively contributed course material and lectures to the international Diploma course of NAASAC, a program that aims to develop systems analysis experience and skills of professionals working as technical experts in ministries or government agencies, either in Egypt or in the region. By the beginning of 2024 one cohort had finished the whole program, and for the future NAASAC has plans to take in two cohorts per year.

Ad 2: Public engagement: secondary schools
Starting in 2024, IIASA is now also strategically engaging with pupils and teachers at secondary schools in order to bring systems thinking skills to students well before they choose their field of university study. For example, about once per month IIASA is offering half-day workshops on systems thinking, resilience and sustainability for visiting school classes [the workshop on the life-cycle of chocolate is a favourite, and the list of schools that have already visited includes one from Finland and the Japanese International School in Vienna. Thus, it is not just Austria as the host country who benefits from this initiative]. In addition, IIASA is also establishing a Climate

Champions program, targeting highly engaged pupils from different secondary schools in the Vienna area and bringing them to IIASA for 4-5 training workshops per year, in order to empower them to bring systems thinking to their peer communities.

For 2025 we are also planning to engage with school teachers and designers of curricula to bring more systems perspectives into classrooms.

Ad 3: IIASA's future: opportunities for our early career researchers
For IIASA to remain agile, relevant and at the forefront of research, it needs to remain attractive as a launching pad for a career in applied systems research, a career that may continue at IIASA or elsewhere. Therefore, as part of the research plan 2021-2024 for the first time identifies ECRs as a focal area for capacity development.

The CDAT unit is coordinating a variety of development activities for ECRs, broadly covering four groups of competencies: (a) general research skills, incl. workshops on statistics, use of AI, programing languages, etc; (b) communication skills, including presentation, writing, and media skills; (c) career advancement, including workshops on how to write successful grant proposals, a mentorship program, networking events, etc (d) systems analysis skills, including an institute-wide reading club on systems analysis; workshops on negotiations, participatory research methods, etc. The CDAT unit is also working towards 'revolving door'collaborations with local (and not so local) universities, to ease the enrollment of junior IIASA staff in PhD programs, and to offer more senior IIASA researchers opportunities to gain teaching experience as university lectures.

The number of early career researchers at IIASA has grown from around 70 in 2020 to around 140 in 2024. In 2023 IIASA offered roughly 40 activities for ECRs for advancing their competences in the four above groups.

8.3. The CDAT Unit

The CDAT unit coordinates CDAT activities, including the YSSP and bilateral postdoc programs, and maintains the communication with group leaders, trainers, and early career researchers in all research groups. It also works closely with the External Relations department and the Directorate on creating opportunities for researchers to come to IIASA or to use IIASA to engage their local systems analysis communities.

In 2024 the CDAT unit internal budget is 300k Euro, which covers 2.6 FTEs (5 part-time staff, incl. 2 senior scientists acting as CDAT Dean and YSSP scientific coordinator, respectively [total: 0.75 FTEs]), a small number of awards and emergency fellowships for the YSSP, and operational costs.

2020	2021	2022	2023	2024
330*	310*	250	265	300

Figure 8-1. Internal CDAT budget (kEuro/year)

Note: In 2020 and 2021 still some postdoc salaries were included.This practice was discontinued in 2022. Not included in the 2024 budget is the 35k for the Summer School on Systems Modeling, which finances itself through registration fees. The budgets of the other three program-centered summer schools in 2024 are also not included in the CDAT unit budget.

The actual leverage of CDAT activities is much larger. A rough estimate indicates that CDAT activities mobilize funds[1] to the tune of 2.7M Euro per year, much of which is covered by IIASA research programs and NMOs/RMOs. Thus, the nominal, compartmentalized budget neither reflects the size of the effort, nor its significance to IIASA.

8.4. SWOT Analysis of CDAT

Strengths • IIASA's CDAT activities are attractive to external partners as they are born out of an international, diverse, and interdisciplinary context and experience that no university or national research organization in a single country can provide. • There is great variety, depth and relevance in a number of systems analytical methods concentrated at the institute that could be taught and disseminated. • The CDAT unit includes practicing senior scientists who are well connected. The unit builds bridges internally across programs and research groups, is solution oriented, and creates a welcoming atmosphere for trainers and trainees.	Weaknesses • Training and teaching is not deeply engrained in IIASA's DNA, and relevant skills do not always correlate with research skills. • The CDAT unit is small and needs to be selective in pursuing the opportunities that are we are approached about or create ourselves. • [Constraints on physical space may be alleviated by the Institute's plan to expand into neighboring facilities.]
Opportunities • IIASA's good reputation and its beautiful venue can be leveraged to host attractive and effective international training programs on global challenges. • There is external demand for training programs in systems analysis and IIASA tools; in some contexts IIASA's unique position as a multilateral and independent organization gives additional credibility and relevance to, inter alia, training programs. • There is room for defining relevant training agendas in an pro-active way. • There are external funding opportunities for training and mobility that are independent of membership contributions and that IIASA can tap into. This requires that CDAT is becoming more entrepreneurial. • Online tools will allow us to offer learning and training modules to wider audiences.	Threats • Absent or weak incentives for IIASA researchers who are serving external research contracts to engage substantially in training activities. • Thus, bottlenecks in expertise as well as in coordinating and administrative support may hamper the scaling of successful activities. • The currently small CDAT unit spreads itself too thinly, given the many demands for coordinating existing and developing further opportunities for learning. • Lack of consensus and support in the IIASA Council to strengthen CDAT activities. In particular, expansion of training activities is not matched by increased financial support by Member Organizations.


International Institute for
Applied Systems Analysis
IIASA www.iiasa.ac.at
International Institute for Applied Systems Analysis (IIASA)
Schlossplatz 1 | A-2361 Laxenburg, Austria
www.iiasa.ac.at
linkedin.com/company/iiasa-vienna
facebook.com/iiasa
youtube.com/iiasalive
twitter.com/iiasavienna
flickr.com/iiasa
blog.iiasa.ac.at
info@iiasa.ac.at