# YSSP22

## A new generation of scientists

Proceedings of the Final Colloquium

Young Scientists Summer Program

IIASA 50
International Institute for Applied Systems Analysis

IIASA's annual three-month Young Scientists Summer Program (YSSP) offers research opportunities to talented young researchers whose interests correspond with IIASA's ongoing research on issues of global environmental, economic, and social change. From June through August each year participants work within the Institute's research programs under the guidance of IIASA scientific staff.

The Proceedings of the Final Colloquium comprises summaries of the research results obtained during the YSSP that were presented at a workshop at the International Institute for Applied Systems Analysis, Laxenburg, Austria, 25–26 August 2022.

The Proceedings are the sole work of the authors with limited or no review by their IIASA mentors or any other staff of the Institute. They are not for publication in the current form. Views or opinions expressed herein do not necessarily represent those of the Institute, its National Member Organizations, or other organizations supporting the work. This compilation contains all the summaries available at the time of finalization of the Proceedings.

**Proceedings editors: Chayasmita Deka, Mel George, Gemma Gerber, Mathilde de Goër de Herve, Linda Ofori, Dan Wang, and Brian D. Fath**

# Contents

Advancing Systems Analysis ..... 8

Biodiversity and Natural Resources ..... 20

Energy, Climate, and Environment ..... 35

Economic Frontiers ..... 46

Population and Just Societies ..... 49

Strategic Initiatives ..... 58

Online Streaming Information

Final Colloquium Day 1 Aug 25, 2022 08:45 AM Vienna
(Wodak) Join Zoom Meeting: https://iiasa.zoom.us/j/97512119286
Meeting ID: 975 1211 9286; Passcode: 711648
(Gvishiani) Join Zoom Meeting: https://iiasa.zoom.us/j/96174125300
Meeting ID: 961 7412 5300; Passcode: yssp1

Final Colloquium Day 2: Aug 26, 2022 08:45 AM Vienna
(Wodak) Join Zoom Meeting: https://iiasa.zoom.us/j/93534552937
Meeting ID: 935 3455 2937; Passcode: 579842
(Gvishiani) Join Zoom Meeting: https://iiasa.zoom.us/j/96924867963
Meeting ID: 969 2486 7963 Passcode: yssp2

| Thursday, 25 August 2022 | | | | | | |
|---|---|---|---|---|---|---|
| **9:00 – 9:10** | ***Welcome and Introduction by CDAT Dean* Fabian Wagner *(Wodak Room)*** | | | | | |
| | **WODAK Room** | | | **GVISHIANI Room** | | |
| **Day 1 - Session 1** | **CARBON** Chair: Peter Rafaj (ECE) | | | **INSTITUTIONS** Chair: Stefan Pietsch (ASA) | | |
| 09:10 – 09:35 | Andreas Lichtenberger | EF/ ECE | Analyzing the income distributional effects of carbon taxation with revenue recycling – case of British Columbia | Junhua Zhu | POPJUS | AI ethics with Chinese characteristics? How the formulations of fairness have evolved with exogenous and endogenous institutional changes in China |
| 09:35 – 10:00 | Pietro Andreoni | BNR | Efficiency and equity implications of trading carbon removal in a net-negative world | Sophie Erfurth | ASA/ BNR | Governing common pool resources in fragile political systems: Modelling behaviour, institutions, and social-ecological dynamics |
| 10:00 – 10:25 | Prerita Agarwal | ECE | Achieving co-benefits from black carbon emissions reductions for north Indian cities using GAINS and WRF – CHEM | Linda Ofori | ASA | How heterogeneity influences institutional change in fisheries: A case study of the Lofoten fishery |
| | ***10:25 – 10:45 BREAK*** | | | | | |
| **Day 1 - Session 2** | **HEALTH** Chair: Muneta Yokomatsu (POPJUS) | | | **DECISIONS** Chair: Adriana Gomez (ECE) | | |
| 10:45 – 11:10 | Aniruddha Deshpande | ASA | Water & sanitation access, flood resilience, and health effects | Swaptik Chowdhury | ASA/ ECE | Exploring equity in energy sector decarbonization policies |
| 11:10 – 11:35 | Thomas Leffler | POPJUS | Land use change and vector-borne disease as an ecological determinant of health: A scoping review | Cindy Giselle Azuero Pedraza | BNR | Integrating biodiversity conservation in forest management decisions |
| 11:35 – 12:00 | | | | | | |
| | ***12:00 – 13:30 BREAK*** | | | | | |

| Thursday, 25 August 2022 | | | | | | |
|---|---|---|---|---|---|---|
| | **WODAK Room** | | | **GVISHIANI Room** | | |
| **Day 1 - Session 3** | **SYSTEMS**<br>Chair: Nikita Strielkovskii (ASA) | | | **CHANGE**<br>Chair: Fabian Wagner (ECE) | | |
| 13:30 – 13:55 | Leonard Kwhang | POPJUS | Integrating stakeholder analysis into qualitative system mapping: An actor-oriented analysis of agritourism networks in Tyrol, Austria | Dipesh Chapagain | ASA/ POPJUS | Attribution of climatic disaster mortality to climatic and socioeconomic changes |
| 13:55 – 14:20 | Xander Huggins | BNR | Global system archetypes for addressing groundwater sustainability challenges and opportunities | Minwoo Park | ECE | The speciated NMVOC emissions change due to emissions control policy and its impacts on air quality |
| 14:20 – 14:45 | Laura Merz | ASA | Supply chain due diligence act for combating unequal exchange: An agent-based modelling approach | Gesang Yangji | ECE | Future scenario of residential hourly cooling energy demand in the United States |
| | ***14:45 – 15:00<br>BREAK*** | | | | | |
| **Day 1 - Session 4** | **AGENTS**<br>Chair: Steffen Fritz (SI) | | | **ECONOMICS**<br>Chair: Rastislav Skalsky (BNR) | | |
| 15:00 – 15:25 | Xinyi Kou | POPJUS | Bilateral international migration measurement and forecast: an agent-based model | Sebastian Franz | ECE | Green transition pathways for the maritime industry – modeling interactions of behavioral and socioeconomic aspects of demand with alternative fueling options |
| 15:25 – 15:50 | Alessandro Taberna | ASA | Integrating top-down and bottom-up risk management strategies against indirect effects of natural disasters: Insights from an agent-based modelling approach | Osamu Nishiura | ECE | Macroeconomic and household impacts of energy transformation pathways for Paris agreement temperature goals |
| 15:50 – 16:15 | Romain Clercq-Roques | SI/ BNR | Coupled dynamics of biodiversity loss and undernutrition in eastern Madagascar: A participatory agent-based model | Chayasmita Deka | ASA | Adoption of electric-vehicles by middle-income Indian population: A comparison of gain & norm motivators & other factors |
| | ***16:15 – 16:30<br>BREAK*** | | | | | |

| Thursday, 25 August 2022 | | | | | | |
|---|---|---|---|---|---|---|
| | WODAK Room | | | GVISHIANI Room | | |
| Day 1 - Session 5 | | | | **RISK**<br>Chair: Alberto Fresolone (POPJUS) | | |
| 16:30 – 16:55 | | | | Olivia Becher | BNR | Global drought risk assessment of water supply utilities and prioritization of adaptation pathways |
| 16:55 – 17:20 | | | | Mathilde de Goër de Herve | POPJUS | Risk justice: boosting risk management contribution to sustainable development |

| Friday, 26 August 2022 | | | | | | |
|---|---|---|---|---|---|---|
| **9:00 – 9:10** | **Welcome and Introduction by YSSP Scientific Coordinator Brian Fath (Wodak Room)** | | | | | |
| | **WODAK Room** | | | **GVISHIANI Room** | | |
| **Day 2 - Session 1** | **NETWORKS** Chair: Brian Fath (ASA) | | | **SCALE** Chair: Reethik Sahu (BNR) | | |
| 09:10 – 09:35 | Dan Wang | BNR | A novel integrated hydro-economic model based on the societal water cycle framework: application to water stress assessment in China | Christopher Wade | BNR | Irrigation as an adaptation measure to climate change in US agriculture |
| 09:35 – 10:00 | Wei Xie | ASA | Ecological network analysis of urban land resource use within China | Xueting Li | POPJUS | Measuring global social vulnerability to natural hazards at the sub-national level |
| 10:00 – 10:25 | Gemma Gerber | ASA | Towards harnessing uncertainty of ecological network indicators in ecosystem management | Dapeng Feng | BNR | Apply deep learning based hydrologic models to rainfall runoff simulation at the global scale |
| | ***10:25 – 10:45 BREAK*** | | | | | |
| **Day 2 - Session 2** | **OPTIMUM** Chair: Stefan Wrzaczek (EF) | | | **BIODIVERSITY** Chair: Jutta Beher (BNR) | | |
| 10:45 – 11:10 | Wenjia Cai | BNR | Leaf area constrained by soil nutrient status with optimality principles | Melissa Chapman | BNR | Spatial prioritization of conservation and restoration measures to meet 2030 biodiversity targets in the EU |
| 11:10 – 11:35 | Maddalena Muttoni | EF | How to prepare and adapt to a climate tipping point | Simon Happersberger | BNR | The integration of biodiversity in preferential trade agreements. A text as data approach to the adaptability of polycentric trade governance |
| 11:35 – 12:00 | Tianyang Lei | ECE | Methane emissions from global abandoned oil and gas wells | Irlan Rum | BNR | Global trade and socio-economic and environmental trade-offs in Indonesia: A study on the future of Indonesian palm oil |

| | | | | | | |
|---|---|---|---|---|---|---|
| | ***12:00 – 13:30 BREAK*** | | | | | |
| **Friday, 26 August 2022** | | | | | | |
| | **WODAK Room** | | | **GVISHIANI Room** | | |
| **Day 2 - Session 3** | **BEHAVIOR** Chair: Adriano Vinca (ECE) | | | **MODELS** Chair: Zuelclady Araujo Gutierrez (BNR) | | |
| 13:30 – 13:55 | Pooja Ramamurthi | ECE | Understanding the relationship between norms, beliefs and appliance ownership in urban India and the U.S. | Hyun-Woo | BNR | Optimization of the IIASA's FLAM model to represent forest fires in South Korea |
| 13:55 – 14:20 | Nora Krenmayr | ECE | From waste to resource? Obstacles and leverage points for a more sustainable e-waste management in the EU | Jan Streeck | ECE | Triangulation of stock-flow indicators of material cycles from MESSAGEIX and industrial ecology |
| 14:20 – 14:45 | Mel George | ECE | Attaining UN SDG-7 for vulnerable households in 1.5 deg C pathways | Tara Ippolito | BNR | Investigating the biophysical determinants of SOC response to management |
| | ***14:45 – 15:00 BREAK*** | | | | | |
| **Day 2 - Session 4** | **OBESITY** Chair: Marta Kozicka (BNR) | | | **FERTILITY** Chair: Jenan Irshaid (POPJUS) | | |
| 15:00 – 15:25 | Zhimin Shi | BNR/EF | Obesity/overweight and environmental impacts: Assessment of excessive food intake in China | Camila Ferreira Soares | POPJUS | Cohort fertility differentials from rural/urban migration in Brazil |
| 15:25 – 15:50 | Lili Kewok Liwin | POPJUS | The causal effect of schooling on overweight/obesity in low- and middle income settings | Marlene Palka | BNR/ASA | Soil data requirements to improve local fertilization strategies – and how to get there |
| | ***END OF COLLOQUIUM RECEPTION IN CONFERENECE AREA*** | | | | | |

# *Advancing Systems Analysis (ASA)*

# Efficiency and equity implications of trading carbon removal in a net-negative world

Pietro Andreoni, Politecnico di Milano and EIEE, Italy
*Email: pietro.andreoni@eiee.org*
IIASA Mentors: Johannes Bednar (ASA), Nikolay Khabarov (ASA), and Michael Obersteiner (BNR)

**Introduction.** Most model-based assessments suggest that stringent climate targets require the deployment of negative emissions technologies to compensate residual emissions or to recover from a budget overshoot. In absence of well-regulated policy mechanisms, the financing of these technologies would result in prohibitive increase in governments' budget deficit. Therefore, intertemporal instruments such as Carbon Removal Obligations have been proposed to finance future removal. However, finding an equitable and efficient geographical distribution of the carbon removal is complex, because the physical and technological potential for carbon removal is heterogeneous. Full international trading of carbon removal obligations would grant an efficient exploitation of this potential, but could lead to large financial flows across countries, raising questions of equity and sovereignty.

**Methodology.** We explore international trading of carbon removal obligations using a highly disaggregated, top-down integrated assessment model. We implement a stylized representation for a representative CDR technology, characterized by regional marginal abatement cost curves. We introduce a regional intertemporal fund for financing net negative emissions. This fund is filled by pricing carbon emissions which exceed emission allowances, grows at the same rate as the economy and is depleted financing negative emissions. Finally, we model an international market for removal obligations, that allows regions to outsource carbon removal by rewarding the target region at the market price. In the context of 1.5°C pathways, we assign regional carbon budget allocations according to different ethical principles. For each allocation, we consider a scenario with and without trading of removal obligations.

**Results** The intertemporal fund required to finance net-negative emissions in the second part of the century accounts for around 30% to 40% of global GDP at its peak in the 2070s, depending on the scenario. Large emitters are the main contributors to the fund because they have more incentive to overshoot the budget, especially if their initial emission quota is low. If trading is allowed (Figure 1), the carbon removal market accounts for up to 15% of the global carbon budget, and it's sensitive to initial allocation. The biggest outsourcing region is OECD, especially in case of a small initial budget (Historical responsibility). For exporters of negative emissions (Africa, Asia), revenues from trading account for around 2% of GDP in the second part of the century.

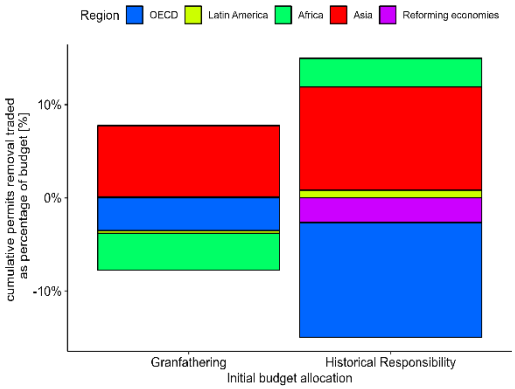



*Figure 1: removal obligations traded as percentage of the total carbon budget in a 1.5°C scenario under different initial budget allocations.*

**Conclusions.** We quantified both the physical and monetary flows involved in a 1.5°C scenario with intertemporal funding and international trading of negative emissions. Both imply relevant but not prohibitive or unprecedented financial flows. Trading carbon removal obligations shifts part of the mitigation burden from large and rich emitters to developing countries with high negative emission potential, but these regions are rewarded with a direct cash flow that compensates the increased costs.

# Attribution of climatic disaster mortality to climatic and socioeconomic changes

Dipesh Chapagain, University of Bonn, Germany
*Email: dipesh@uni-bonn.de*
IIASA Mentor: Dr. Reinhard Mechler (ASA) and Dr. Samir K.C. (POPJUS)

**Introduction.** The socio-economic impacts of climate-related disasters have been rising globally. Several studies argue that this upward trend is due to rapid growth in population and wealth exposed to disasters. Others argue that increases in intensity, frequency, and duration of extreme weather events due to anthropogenic climate change are responsible for the rise. While disaster impacts, such as loss of human life as its most severe consequence, are felt more acutely in low-income countries, existing studies are mostly from developed countries or at the cross-country level. To address these scientific and policy-relevant questions in context, we assess the attribution of landslide and flood mortality to indicators of climatic hazards, exposure, and vulnerability in a low-income country Nepal.

**Methodology.** We employ disaster-specific generalized linear models to study the attribution of landslide and flood mortality. Our variable of interest is observed 30-year (1992-2021) annual disaster mortality at the scale of 753 local administrative units of Nepal. As explanatory variables, we used extreme precipitation indices, population density, and per capita income (PCI) as indicators of hazards, exposure, and vulnerability respectively following a climate risk framework.

**Results.** Extreme precipitation indices showed mixed trends across Nepal. It has increased in the relatively dry western region but decreased in the central mid-hills. Landslide and flood mortality, which accounts for 70% of climatic disaster mortality in Nepal, has increased in the past 30 years. We found a positive and mostly significant association of disaster mortality with extreme precipitation duration (consecutive wet days - CWD), frequency (number of heavy rain days – R10mm), and intensity (maximum 1-day precipitation – RX1day). One unit (one standard deviation from the mean) increase in CWD increases flood mortality by 46% (ceteris paribus). Similarly, one unit increase in RX1day increases landslide mortality by 35%. The association is negative with the PCI as a proxy for vulnerability. A unit increase in PCI decreases landslide mortality by 22% and flood mortality by 61%. Population density does not show a significant association with disaster mortality (Fig. 1).

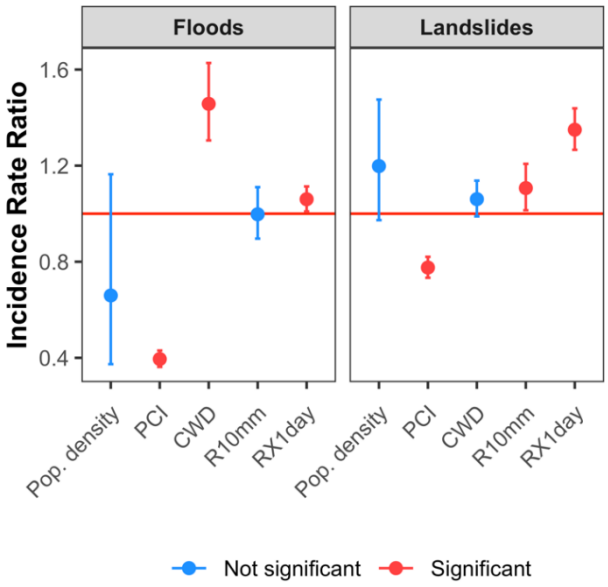



***Fig. 1**: Incidence rate ratio (95% confidence interval) estimated from Poisson models with no. of people died as dependent variable. Independent variables (shown in x-axis) are in standardized Z-score and significance at p = 0.05 level.*

**Conclusions.** The precipitation pattern has changed in Nepal and many regions have experienced an increase in extreme precipitation indices. Such indices have also shown a significant positive association with disaster mortality. Income growth as a proxy of vulnerability is negatively associated with mortality, and we did not find a significant role of exposure to disaster mortality. Hence, the observed rise in disaster mortality could be largely attributed to the rise in precipitation extremes due to climate change. The projected rise in precipitation extremes is most likely to increase mortality in the future if no actions are taken to strongly reduce the vulnerability.

# Exploring equity in energy sector decarbonization policies

Swaptik Chowdhury, RAND Corporation, USA
*Email: schowdhu@pardeerand.edu*
IIASA Mentors: Piotr Żebrowski (ASA) and Elina Brutschin (ECE)

**Introduction.** A rapid transition to clean energy for energy sector decarbonization requires robust equity considerations because unmanaged decarbonization may entrench systemic inequities among disadvantaged and vulnerable communities. Thus, the concern for equity in the transition process and its outcome is of key importance. For example, phasing out the use of coal for electricity generation is one of the potential strategies suggested for meeting emissions standards and achieving decarbonatization of the energy sector. Rapid and unmanaged phaseout, however, can lead to unemployment and other equity concerns. Thus, there is a need for a model-centric approach that allows connecting qualitative equity considerations with quantitative models used to design strategies for decarbonization of the energy sector such as coal power phaseout.

**Methodology.** This study aims to identify formal requirements for using equity principles in model-centric planning. Thus, the goal of this study is to identify relevant qualitative equity principles guiding the appraisal of policies for phasing out of coal-fired power plants and to demonstrate how these principles could be formalized and used within quantitative modeling frameworks. We conducted a scoping literature review of existing environmental justice and energy equity principles and identified different shapes of justice and components of equity. "Capacity-Coal" output from a MESSAGE scenario run was then used to calculate the target reduction in the use of coal for electricity generation. Leveraging the global energy monitor's Coal power plant data[1], relevant equity metrics were developed for the selected shapes of justice: utilitarianism, egalitarianism, and sufficientarianism. We use these metrics to develop a ranked order of equitable phase-out of coal powerplants under different shapes of justice and with the objective of achieving the desired reduction in the use of coal for power generation.

**Results.** The literature review revealed that much of the literature on energy equity focused only on the normative application of equity and lacked clarity on metrics and indicators which can be used to measure equity for a quantitative decision-making process. We also noticed that much of the literature converges on three components of energy equity: distributive equity, procedural equity, and contextual equity. For this study, we focus only on distributive equity. We identified "annual CO2/capacity of powerplant", "remaining plant life" and "decent living standard (DLS)" as metrics for utilitarianism, "annual CO2", "lifetime CO2" & "remaining plant life" as metrics for egalitarianism, and "annual CO2", "lifetime CO2", "dls", "share of the coal mining industry in GDP", and "remaining plant life" as metrics for sufficientarianism. We also explored the use of composite variables (developed using metrics) for aiding in making decision-making. Composite variables were developed with a focus on easy stakeholder engagement and transparency during decision-making.

**Conclusions.** The study establishes a method that is easy to apply in different contexts to aid model-centric and equitable management of various transition processes. This study develops a general framework by identifying different components of equity that are important for decision-making under different shapes of justice. The study also demonstrated the applicability of the framework by applying the framework to develop metrics (considered under the different shapes of justice) for measuring equity outcomes of coal powerplant output phase-out policy.

**References**

Global Energy Monitor. (2022, July 29). Global Coal Plant Tracker. https://globalenergymonitor.org/projects/global-coal-plant-tracker/

# Adoption of electric-vehicles by middle-income Indian population: A comparison of gain & norm motivators & other factors

Chayasmita Deka, Indian Institute of Technology Guwahati, India
*Email: cdeka@iitg.ac.in*
IIASA Mentors: Nadejda Komendantova (ASA) and Masoud Yazdanpanah (ASA)

**Introduction.** Since 2013, the Government of India has made efforts to decarbonize the transport sector by launching several electric vehicle (EV) diffusion policies. Though the units of EV sold has recorded an increase in the year 2020-2021, it is extremely negligible as compared to the rising demand for petrol and diesel vehicles. This increasing demand needs to be converted to demand for EVs, considering that demand for personal vehicles will continue to increase in the future, with the growing incomes and aspirations of people. Under recurring instances of technical failure of e-bikes, cost concerns, social network influence, etc., we aim to examine how intentions form in the minds of people and whether it is gain, norm, or protection motivation that influence intention to adopt EV. To achieve this goal, we apply three environmental psychological models: Theory of Planned Behavior (TPB), Norm Activation Model (NAM), and Protection Motivation Theory (PMT).

**Methodology.** Our population of interest is the middle-income group, within age 18-60. We collected 320 samples from eastern India using random and convenience sampling. Structural equation modelling (SEM) is used to explore the determinants of intention. We propose several models of intention formation in India, based on TPB, NAM, and the PMT model, and their extensions. We established fit (reliability and validity) with our empirical data using CFA for each measurement model. We also developed scales for two new latent constructs, namely herd behavior and cost. Then the structural models have been established using AMOS. This is followed by mediation analysis using Process Macro to examine the stepwise intention formation process through both direct and indirect routes.

**Results.** From the CFA analysis we infer that the measurement models used in our study indicate acceptable reliability, validity, parsimony, and fit. The newly developed scales for herd behavior and cost have been established. From the SEM analysis, it has been found that subjective norm is the strongest direct determinant of intention in India. Other than that, ascription of responsibility, perceived behavioral control, response efficacy, perceived vulnerability is found to have a direct impact on intention. Attitude, personal norm, environmental concern is found to have a useful mediating effect where, these variables facilitate intention formation through indirect route. Herd behavior and personal norm are found to be fully mediated by subjective norm; awareness of consequence is fully mediated by perceived vulnerability; and environmental concern is fully mediated by personal norm. Subjective norm and protection motivators are found to have the greatest impact on intention formation as compared to gain motivators or other norm motivators.

**Conclusions.** The present EV promotion schemes of the government are not well targeted. Majority of the states have announced some subsidy on the initial purchase, while cost is only found to influence intention through an indirect route after perceived behavioral control and attitude has been triggered. Hence, there is a possibility of government investment to be wasted, as it will not be very effective in nudging the people who have a low initial intention to buy an EV towards actual EV purchase behavior. In terms of energy policy for India, our study strongly recommends re-designing its schemes to trigger subjective norm and ascription of responsibility which are found to be the most powerful determinant of intention among the middle-income group in India. This study proposes several policy recommendations for cost-effective, and efficient EV promotion in India.

# Water & sanitation access, flood resilience, and health effects

Aniruddha Deshpande, MPH, Emory University, USA
*E-mail: avdeshp@emory.edu*
IIASA Mentors: Josephine Borghi (ASA) and Georg Pflug (ASA)

**Introduction.** According to the International Panel for Climate Change (IPCC), extreme weather events are expected to increase in frequency and intensity partially due to climate change. Floods are one of the most common forms of extreme weather events representing a major cause of health burden and economic costs. A direct health consequence of flooding is gastrointestinal illness, often due to contaminated water supplies. Gastrointestinal diseases are the third leading cause of under-5 mortality in low-income countries. Therefore, a small proportional increase in incidence due to flooding could lead to a large loss of human life.

Water and sanitation (WASH) infrastructure is a key mediator in how floods have community health impacts. Highly resilient WASH infrastructure may reduce the impact of flooding via gastrointestinal illness as it would prevent contamination and supply disruption. Safe WASH in the form of piped water supply and sanitation, could be more resilient to flooding compared to surface drinking water or pit latrines. Furthermore, safe WASH is associated with a lower risk of gastrointestinal illness compared to unsafe WASH. Therefore, we aim to assess whether increases in access to safe WASH are associated with flood resilience as defined by reduced service disruptions after a flood.

**Methodology.** We utilized data from the Flood Resilience Measurement for Communities (FRMC) tool. The FRMC is a community driven self-assessment tool. It assesses the resilience of a community to floods across five different capitals at two time-points (baseline and endline). Furthermore, select communities also conduct a survey if there is a flood to measure flood-performance of certain systems (post-event survey). We focused on measurements of flood-related WASH service disruptions in the baseline and endline surveys in addition to WASH service disruptions in the post-event survey. To assess community access to WASH we utilized data from the Global Burden of Disease Study. The dataset contains fine-scale geospatial estimates of population access to safe WASH.

We conducted correlation analyses between access to WASH and flood resilience of WASH at baseline across the FRMC communities. By doing so, we assessed whether there is an association between the geographic variation in access to WASH and flood resilience across communities. We conducted a similar analysis to assess the association between WASH access and flood resilience of WASH as measured by the post-event survey. Furthermore, we conducted correlation analyses between changes in WASH access and how flood resilience changed between baseline and endline in the communities.

**Preliminary Results & Discussion.** We found substantial variation in flood resilience, as defined by lack of WASH service disruption, across communities in the FRMC. Many communities reported lower service disruption for drinking water supply at endline compared to baseline. The same trend was not as clearly observed for sanitation services. This may highlight the importance of local contextual factors influencing WASH performance and the differential challenges between water versus sanitation development.

# Governing common pool resources in fragile political systems: Modelling behaviour, institutions, and social-ecological dynamics

Sophie Erfurth, University of Oxford, United Kingdom
*Email: sophie.erfurth@sjc.ox.ac.uk*
IIASA Mentors: Matthias Wildemeersch (ASA), Taher Kahil, and Reetik-Kumar Sahu (BNR)

**Introduction.** Groundwater user groups in Tunisia face severe collective action problems (Frija, 2014). Aquifer depletion leads to empty wells and farmers' unwillingness to pay water fees leads to bankrupt user groups – both disastrous for the many communities that rely on irrigation agriculture for their livelihoods. What conditions or combination of conditions drive water user behaviour in a fragile political context that has seen the near complete erosion of institutional trust? What conditions or interventions are effective in avoiding or delaying system collapse? What is the role of social norms, particularly trust and leadership, in overcoming collective action problems?

**Methodology.** The complex common-pool resource (CPR) system is simulated by coupling an agent-based model (ABM) of user decision-making to a surrogate hydrogeological model. Social data stems from semi-structured interviews and focus group discussions conducted in May 2022, and physical data from established MODFLOW and WEAP models of the study region. In the ABM, groundwater users create agricultural profits by cultivating crops and using the CPR to irrigate. The utility of farmers, however, is not solely driven by cashflows but is further affected by vertical (trust in government and leadership) and horizontal (social cohesion and reputation) institutional arrangements. Utilities suffer penalties based on deviations from these social norms, i.e. if individual actions are not in agreement with the accepted set of rules. Farmers are able to make two decisions: How much water to withdraw illegally (on top of legal allocations), and whether or not they pay their fees to the user group. Social status within the user group impacts the evolution of social norms. Specifically, in each cropping cycle farmers can change their strategy by imitating the actions of one of the best performing members of the user group.

**Results.** The model simulates two types of system collapse: (i) hydrogeological collapse that occurs when hydraulic heads go below critical threshold level, and (ii) financial collapse when the user group is shut down due to their inability to cover pumping costs. These two crashes represent two collective action problems: Overexploitation of ground-water resources and farmers' unwillingness to pay groundwater fees. Similarly to thresholds for hydraulic heads and group finances, the model further installs a poverty threshold to the user profit function to understand livelihood dynamics. While exceeding this threshold does not crash the system of groundwater extraction, it is an indicator of the social sustainability of the system. With this framework, we can study (i) the long-term trends and sustainability of water extraction practices, (ii) the collective action outcomes related to illicit water extraction and user group management under different scenarios, (iii) pathways that delay or inhibit system collapse, and (iv) insights into effects on farmers' livelihoods (what share of farmers live below the poverty threshold?).

**Conclusions.** The model offers a novel approach to simulate interactions between human behaviours, social norms, and a dynamic resource system. The differentiation between types of trust and social drivers of decision-making gives a glimpse into a CPR system that is governed by institutional uncertainty and bounded rationality. Tracing the convergence of asynchronous farmer decisions towards community strategies as a response to community interventions offers valuable insights into potential policy pathways.

## References

Frija, A., A. Chebil, S. Speelman, and N. Faysse (2014) 'A critical assessment of groundwater governance in Tunisia', Water Policy, 16, 2, 358-373.

# Towards harnessing uncertainty of ecological network indicators in ecosystem management

Gemma Gerber, University of KwaZulu-Natal, South Africa
*Email: gemmagerber@live.com*
IIASA Mentors: Elena Rovenskaya (ASA) and Brian Fath (ASA)

**Introduction.** Quantitative assessments of ecosystem function are often investigated through Ecological Network Analysis (ENA) of food web models, resulting in indicators that describe different aspects of ecosystem-level properties. Ecosystem indicators can be calculated on a single empirically based network solution, however this may not be representative of the overall system's natural functional variability. Ecosystem modelling has evolved to incorporate variability of empirical data through ensembles of plausible network solutions. Each plausible solution is valid within the constraints of the ecological data, introducing uncertainty in the model outputs describing ecosystem function (Hines et al., 2018). We aimed to investigate if ecosystem indicators calculated from single and ensemble network solutions are representative of ranges of ecological input data describing the ecosystem.

**Methodology.** Using a case study system of uMdloti Estuary, South Africa, we constructed thirteen monthly food web models (2015 – 2016) to serve as a basis for our investigation. Two linear inverse modelling (LIM) algorithms commonly accepted by ecologists ("central" and "least squares with equalities and inequalities") (Van den Meersche et al., 2009) were used to calculate single network solutions for each model. These solutions were complemented by ensembles of 10,000 plausible network solutions solved using LIM coupled with Markov Chain Monte Carlo. Ecological Network Analysis (ENA) was applied to all solved networks. We compared pairwise relationships of ENA indicators, understood as ecologically related, derived from each solution type to establish each solution type's representation of ranges of ecological input data.

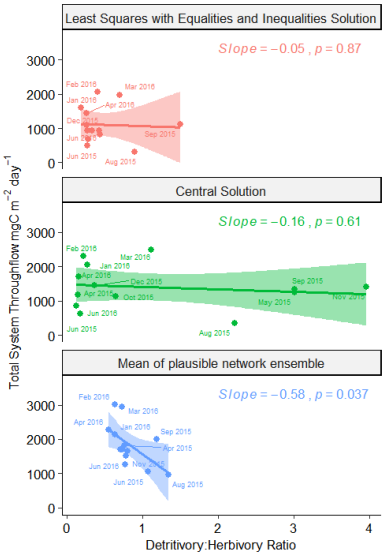



*Figure 2: Relationships between ecosystem indicators derived from single network solutions, and ensemble solutions. Detritivory:Herbivory Ratio describes the importance of the first trophic levels for energy. Total System Throughflow (mgC $m^{-2}$ $day^{-1}$) describes the relative size or activity of the system. Greater values for each indicator can describe a system that is more resilient to perturbations.*

**Results and Conclusions.** Among multiple pairs of ENA indicators, several correlations differed between single network solutions and mean ensembles of plausible network solutions. For the specific case presented (Van den Meersche et al. 2009), significant correlations between indicators are not reflected in the single network solutions. Significant linear correlations between indicators using ensemble means show that the "crowd wisdom" of ensemble solutions are closer estimates of ecological reality. Where relationships between indicators from ensemble means show no difference to single network solutions, we encourage further exploration of ensemble methods capacity to allow for more robust inferences of ecosystem status. More robust inferences of ecosystem status through ensemble methods potentially enhances data-driven decision making and good ecosystem management practices.

## References

Hines, D. E., Ray, S., & Borrett, S. R. (2018). Uncertainty analyses for Ecological Network Analysis enable stronger inferences. *Environmental Modelling & Software*, *101*, 117–127. https://doi.org/10.1016/J.ENVSOFT.2017.12.011

Van den Meersche, K., Soetaert, K., & Oevelen, D. Van. (2009). xsample() : An R Function for Sampling Linear Inverse Problems. *Journal of Statistical Software*, *30*(Code Snippet 1). https://doi.org/10.18637/jss.v030.c01

# Supply chain due diligence act for combating unequal exchange: An agent-based modelling approach

Laura Merz, ESCP Berlin, Germany
*Email: lmerz@escp.eu*
IIASA Mentor: Célian Colon (ASA)

**Introduction.** Unequal exchange is a significant feature of economic globalisation which allows benefitting from price differences to grow profits whilst associated environmental and social costs are externalised to countries of production. In an attempt to acknowledge the asymmetric interdependencies, the new German Supply Chain Due Diligence Act ('Lieferkettensorgfaltspflichtengesetz' (LkSG)) obliges globally operating German firms to reduce local environmental harm and improve labour conditions of production processes through the establishment of risk management systems (Deutscher Bundestag, 2021). The ambitiousness of the LkSG is analysed by investigating whether the proposed regulatory measures of the policy show an effect in combating unequal exchange. The LkSG comes into force on the 1st of January 2023, adding to the actuality of the research. Assessing the effectiveness of the policy is a relevant research endeavour as the LkSG and its Dutch and French counterparts will serve as blueprints for the planned European-wide supply chain law.

**Methodology.** This project is based on the three-sector and two-region agent-based macroeconomic model by Gerdes et al. (2022) which depicts dynamics of economic unequal exchange along a stylised global value chain. The model was stripped down to its core, focusing on local pollution due to resource extraction and the associated poor labour conditions in the Global South. Key measures of the LkSG are added to the model, i.e., establishment of an institutionalised whistleblowing mechanism, randomised audits, fines targeted at firms in the Global North that trade with non-compliant mines, updating trading partners in the case of abducted non-compliance, and preventive measures.

**Results.** We find that the measures introduced through the LkSG stimulate mines in the Global South to innovate. More innovation leads to lower pollution rates from mining and higher productivity of mine workers, a proxy for health. These productivity gains generate higher profits in the long run, making further innovation easier to finance. Foresight and long-term planning is not a characteristic of utility maximising firms in global market dynamics which is countered through the establishment of preventive measures within an LkSG scenario. Additionally, the introduced fine system curtails profits in the Global North and creates opportunities for mines in the Global South to grow. Converging profit rates similarly lead to a reduction between wage gaps, countering uneven terms between the regions.

**Conclusion.** We found that the binding measures planned in the LkSG can initiate the reduction of environmental impacts through mines as well as improve the health and livelihood of mine workers. Our results show that the LkSG is an attempt to combat the unequal exchange along global value chains. Such policies help direct the financial benefits of the Global North toward reducing their externalised environmental and social costs, thereby promoting more equal exchange with the Global South.

## References

Deutscher Bundestag. (2021). *Entwurf eines Gesetzes über die unternehmerischen Sorgfaltspflichten in Lieferketten* (19/28649; Gesetzesentwurf Der Bundesregierung). https://dserver.bundestag.de/btd/19/286/1928649.pdf [last accessed on 17.08.2022]

Gerdes, L., Rengs, B., & Scholz-Wäckerle, M. (2022). Labor and environment in global value chains: An evolutionary policy study with a three-sector and two-region agent-based macroeconomic model. *Journal of Evolutionary Economics*. https://doi.org/10.1007/s00191-021-00750-7

# How heterogeneity influences institutional change in fisheries: A case study of the Lofoten fishery

Linda Ofori, Wageningen University and Research, Netherlands
*Email: linda.ofori@outlook.de*
IIASA Mentors: Nikita Strelkovskii (ASA), Ulf Dieckmann (ASA), and Mikko Heino (ASA)

**Introduction.** Fisheries are subject to a multitude of external shocks such as climate change or economic crises, affecting the livelihoods dependent on them and potentially forcing many to search for new means to sustain their livelihoods, elsewhere. As displaced resource users resort to the extraction of less affected resources, newly formed groups of resource users become more heterogeneous, potentially creating new challenges or opportunities for the management of such resources. Thus, effective governance which can ensure sustainable resource use, in the face of external shocks, requires a better understanding of how heterogeneity among resource users affects cooperation and compliance.

**Methodology.** We study how socio-cultural and economic heterogeneity affects cooperation and compliance in fisheries by using a combination of econometric analysis, agent-based modelling and social network analysis. The Lofoten fishery in Norway serves as our case study, providing us with data from annual reports for the period 1857-2011, which we combine with data from other national reports. We start by testing the statistical significance of different forms of heterogeneity in fixed effects negative binomial regression models, in order to identify a set of stylised facts. The identified stylised facts form the basis for our agent-based model (ABM). Agent-based modelling allows us to investigate how increased heterogeneity among resource users affects collective behaviour in fisheries and how it may give rise to potential tipping points at which an existing social norm erodes or a new one emerges.

**Preliminary findings.** We tested the effect of different forms of heterogeneity on compliance, as proxied by the number of violations committed in the Lofoten fishery. We find that a unit increase in the coefficient of variation of religious affiliations in the fishers' home counties raises the number of violations committed by a factor of 16.4, when other model variables are held constant. Similarly, a unit increase in the coefficient of variation in income of the fishers' home counties raises the number of violations committed by a factor of 5.5, when other model variables are held constant. However, heterogeneity in fishing experience in the fishers' home counties was not found to have a significant effect on the number of violations committed.

**Conclusion**. Our findings suggest that both socio-cultural heterogeneity, in terms of religious affiliations in the fishers' home counties, and economic heterogeneity, in terms of incomes in the fishers' home counties, decrease compliance in fisheries. These findings are corroborating results in the existing theoretical and empirical literature on the role of heterogeneity in common-pool resource management (Bardhan, 2000; Bardhan & Dayton-Johnson, 2002). They highlight the importance of gaining a better understanding of the increased heterogeneities in fisheries that may be induced by external shocks such as economic crises and climate change for resource management in small-scale fisheries.

### References

Bardhan, P. (2000). Irrigation and cooperation: An empirical analysis of 48 irrigation communities in South India. *Economic Development and Cultural Change*, *48*(4), 847–865.
Bardhan, P., & Dayton-Johnson, J. (2002). Unequal irrigators: Heterogeneity and commons management in large-scale multivariate research. In *The Drama of the Commons* (pp. 86–112). National Academy Press.

# Integrating top-down and bottom-up risk management strategies against indirect effects of natural disasters: Insights from an agent-based modelling approach

Alessandro Taberna, Delft University of Technology, The Netherlands
*Email: a.taberna@tudelft.nl*
IIASA Mentor: Stefan Hochrainer-Stigler (ASA)

**Introduction.** As a result of climate change, the intensity and severity of floods are increasing worldwide. The new climate reality poses a systemic threat and requires policy-makers to facilitate climate change adaptation (CCA) at all levels of society. Hence, models that accurately assess damages and compare the costs and benefits of multiple CCA strategies are crucial for effective climate policy-making. Agent-based models (ABMs) have been increasingly used for flood risk management strategies. However, despite advancing our understanding of risk, these tools still face several limitations. In particular, they remain household-centered and overlook the role of firms and indirect losses generated by business interruption, losses of employment opportunities, and tax revenues.

**Methodology.** To capture indirect damages from floods, we present a novel version of the Climate-economy Regional Agent-Based (CRAB) model[1]. The CRAB model combines households and firms in a regional economy, where they interact via market institutions, migration, climate, and technological learning. This rich set of interactions allows mapping feedback loops and cascading effects generated by flood shocks. In addition, using rich behavioral data[2], we include a risk layering strategy with bottom-up and top-down adaptation strategies ranging from individual risk reduction to insurance[3]. We parametrize the model to an archetype of the coastal megacities of Shanghai.

**Results**. We validate our model with its ability to replicate a wide range of micro and macro stylized facts. Our results show how flood damages can undermine economic well-being. In addition, we quantitively display how synergies between CCA strategies represent the best chance to build climate-resilience societies. In particular, the design of a risk layer approach with both bottom-up and top-down risk management strategies allows for redistribution of flood risks and, if combined with a timely mitigation strategy, possibly transforms losses into long-term opportunities for economic growth and development. However, simulation results show that a close sequence of very extreme shocks might require more than the available resources, with devastating consequences for the regional economy.

**Conclusions.** The CRAB model provides a general understanding of the importance of a comprehensive framework that includes both firms and households and how their interactions, as well as cumulative individual actions, shape regional climate-induced damage and resilience. Importantly, the model shows how synergies of adaptation actions undertaken at all levels of society offer the best chance to tackle the rising climate threat. Crucially, the integration of local risk management strategies with top-down approaches offers new ways forward to tackle not only the direct but also indirect risk in an explicit way and therefore offers new ways forward how to transform emerging risk challenges into long-term opportunities.

## References

1. Taberna, A., Filatova, T. & Roventini, A. Shifting faith of coastal economies : regional evolutionary agglomeration dynamics in face of climate-induced hazards. 1–2 (2021).
2. Noll, B., Filatova, T., Need, A. & Taberna, A. Contextualizing cross-national patterns in household climate change adaptation. *Nat. Clim. Chang. 2021* 01222, 1–6 (2021).
3. Hochrainer-Stigler, S. & Reiter, K. Risk-Layering for Indirect Effects. *Int. J. Disaster Risk Sci.* 12, 770–778 (2021).

# Ecological network analysis of urban land resource use within China

Wei Xie, Fudan University, China
*Email: wxie18@fudan.edu.cn; xiewei@iiasa.ac.at*
IIASA Mentors: Brian Fath (ASA) and Saige Wang (ASA)

**Introduction.** In the past decades, expansive and rapid land cover change for human uses has been a key driver of environmental and societal stresses. In particular, urban areas, as the priority place of industrial and economic activities, are responsible for major greenhouse gas emissions and resource consumption despite their small physical footprint. However, how land resources are used and allocated within industrial and socio-economic urban areas is still unclear. In this study, we conduct ecological network analysis (ENA) to identify, from a systems perspective, the resource usage patterns, drivers, and virtual flow pathways.

**Methodology.** Based on a pre-established multi-regional and multi-sectoral land use dataset, an ecological network model was applied to study the interwoven connections among sectors and regions in China for the year 2012. Environmentally extended input-output analysis was used to evaluate the land resource flow, and ecological network analysis was adopted to evaluate the network properties of each region of China. The investigation comprised 31 Chinese provinces due to data availability. Each province or municipality was handled as a separate network in the ENA, with 42 economic sectors as nodes. One research novelty is using direct land flows between sectors as nodal flows. Foreign import flows were ignored due to a lack of data on land intensity.

**Results.** The land footprint on the production side of the country's 31 provinces totalled 3.67 million hectares in 2012. Guangdong, Shandong, and Jiangsu province remained the three highest provinces of land footprint from both production and consumption side. The land footprint varies by provinces, with the top six accounting for 50.87% of total national land use on the production side and 45.05% on the consuming side. High production-based footprints were mainly found in the east coastal provinces, with high industrial development, while high consumption-based footprint was mainly related to the provincial population. The industrially developed provinces, as the main virtual land outflow areas, also exhibit a more complex network structure, with higher total system throughflow, more resource flow pathways, longer path length, and greater circularity.

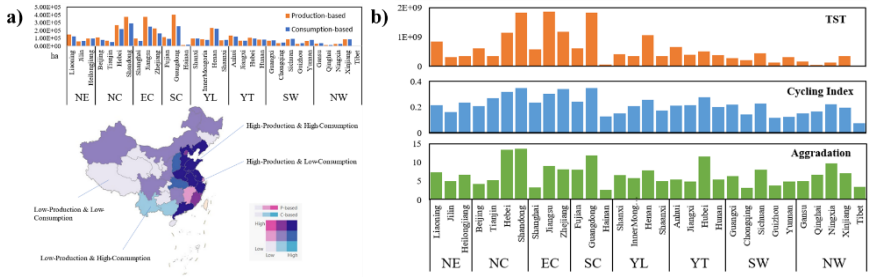



Figure 1: Provincial land footprint and network properties within China. a) Provincial land footprint from production and consumption-based perspective. b) Three network properties: total system throughflow (orange), cycling index (blue), and network aggradation (green) of provinces. All data are for 2012. The abbreviations: NE, northeast; NC, north coast; YL, Yellow River midstream; YT, Yangtze River midstream; EC, east coast; SC, south coast; SW, southwest; NW, northwest.

**Conclusions.** This study explores a new method of using land flows in environmentally extended IO analysis and ENA to assess China's land use footprint from both the production and consumption perspectives. The result shows that land resource use exhibits a high degree of spatial concentration and heterogeneity, supplied domestically by the eastern coastal provinces and transferred to the western provinces. This study helps to understand the operation and future land demand of urban systems.

# *Biodiversity and Natural Resources (BNR)*

# Integrating biodiversity conservation in forest management decisions

Cindy Azuero Pedraza, Georgia Institute of Technology, USA
*Email: cpedraza3@gatech.edu*
IIASA Mentor: Andrey Lessa (BNR) and Lauri Pekka (BNR)

**Introduction.** Forests play a major role in two of the biggest challenges humans face today, climate change and biodiversity loss. Increased interest in nature-based solutions, the expectation of increased dependence on negative emission technologies such as Bioenergy with Carbon Capture and Storage (BECCS), and biodiversity conservation goals, puts forest management and land use change decisions in the spotlight. Forest and land management decisions respond to economic incentives of landowners or forest managers, but frequently ignore the related biodiversity impacts. Here, we tackled this issue and included biodiversity impacts in forest management decision making, in a spatially explicit manner, by incorporating the countryside species area relationship (cSAR) model into the global forest sector model GLOBIOM-forest.

**Methodology.** We integrated the cSAR model, into the partial equilibrium GLOBIOM-forest model. Using cSAR, potential regional species loss was estimated for each ecoregion and taxa on a global basis, as a response to changes in forest management intensities (low, medium, and high). We assessed the effects of constraining biodiversity in comparison with a baseline run of the model. Indicators of interest included, harvested areas, location and forest management type used, supplied quantities of forest products, trade, and species loss.

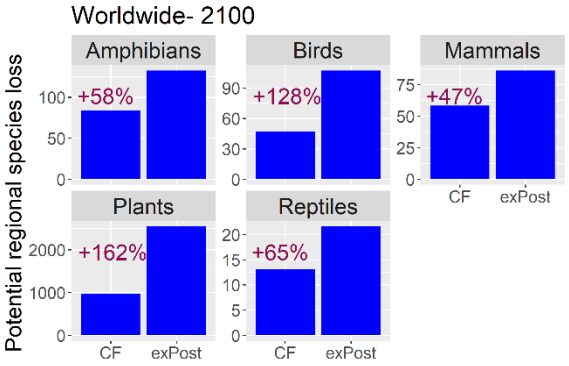



*Figure 3*

**Results.** Initial results (Figures 1 & 2) indicate that (1) omitting biodiversity loss implies between 47% to 162% additional species loss for 2100 depending on the taxon, (2) when adding biodiversity, global harvest volumes of roundwood do not decrease significantly and (3) there is an increase in high intensity and a decrease in medium intensity management in some boreal forests. Furthermore, we observed an increase in low intensity management in the northwest of Russia and some tropical areas.

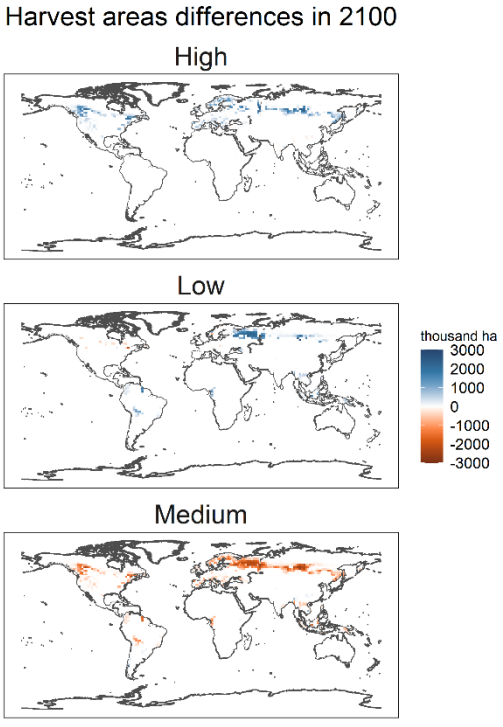



*Figure 5*

**Conclusions.** Omitting biodiversity loss into forest management decision making result in significantly higher impacts on biodiversity, compared to a scenario where biodiversity is endogenized. The results magnitudes vary by taxa and biodiversity method used and depend on the spatial allocation of management intensities. With this type of integrated ecological-economical approach, potential solutions that favour both biodiversity conservation and forest industry economic outputs could be identified. Initial results will be improved by (1) assessing different climate change mitigation scenarios, (2) incorporating additional biodiversity indicators, (3) extending the framework to also include land use change and (4) evaluating additional methods to incorporate biodiversity in the model.

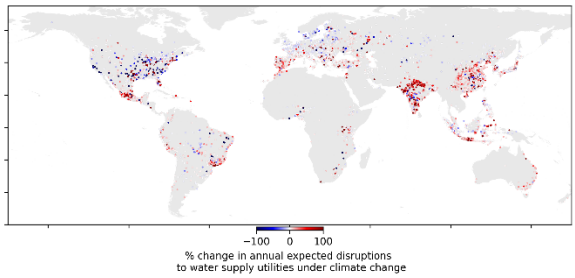
# Global drought risk assessment of water supply utilities and prioritization of adaptation pathways

Olivia Becher, Oxford University, UK
*Email: olivia.becher@ouce.ox.ac.uk*
IIASA Mentors: Mikhail Smilovic (BNR) and Sylvia Tramberend (BNR)

**Introduction.** Drought-induced disruptions to critical water supply services impose a heavy burden on connected households, hindering progress towards the Sustainable Development Goals (UN, 2021). However, large-scale drought risk analysis of utility (household) water supply is lacking. Here, we propose a novel risk assessment framework to perform drought risk analysis of global water supply utilities and evaluate the marginal benefit (i.e., risk reduction potential) of alternative infrastructure investment scenarios.

**Methodology.** To estimate present and future drought risk, we construct a monthly water balance for 6700 water supply utilities (GWI), globally, under present and future conditions of climate change. We use the Community Water Model (Burek *et al.*, 2017) output variables to simulate the water supply available to each utility. The demand that is vulnerable to drought for each utility is found as a function of population served, per capita consumption, desalination inputs and leakage losses (FAO, 2020; GWI, 2022). Where the supply is not sufficient to meet the demand, we estimate the effective severity of drought-induced customer disruptions. The simulated monthly extent of disruption is converted to an annual present day and future risk value. The risk reduction benefit of implementing alternative adaptation options (including leakage reduction and desalination capacity increase) is evaluated by comparing the risk output with and without the influence of each intervention on the water balance. Thus, the benefit of options can be weighed against their costs to offer insights into the most cost-effective adaptation pathway.

**Results.** *Preliminary* results provide the spatial variation of the impact of climate change on customer disruption risk. Our preliminary analysis suggests that, where applicable, desalination offers a higher marginal benefit compared to leakage reduction. However, this does not account for operational costs, which are significantly higher for desalination than for leakage reduction, which would, in effect, offer efficiency gains for utilities.




**Conclusions.** The proposed framework provides a useful advance in the drought risk analysis and water infrastructure investment needs literature. Adopting the water supply utility scale as the unit for analysis, we provide a tangible assessment of risk as a platform for comparing alternative potential adaptation pathways.

## References

1. Burek, P. et al. (2017) 'The Community Water Model (CWATM) / Development of a community driven global water model', in *European Geosciences Union General Assembly 2017*.
2. FAO (2020) AQUASTAT. Available at: *http://www.fao.org/aquastat/statistics/query/index.html* (Accessed: 10 March 2021).
3. GWI (2022) GWI WaterData.
4. UN (2021) The sustainable development goals report 2019, United Nations publication issued by the *Department of Economic and Social Affairs.*

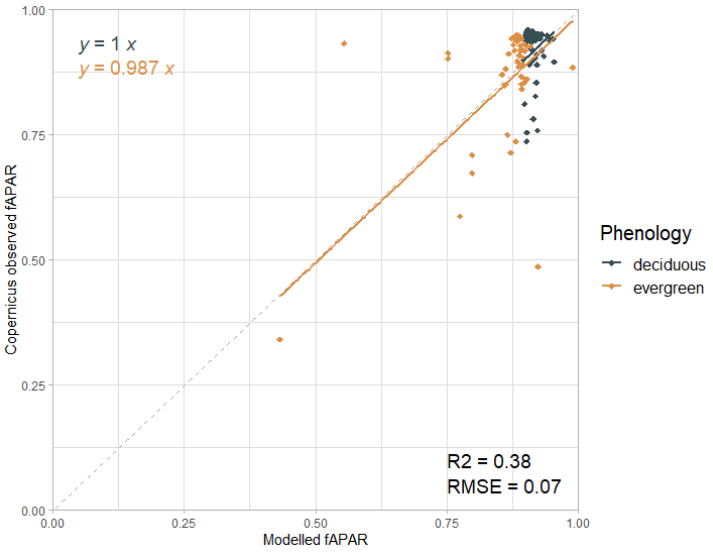
# Leaf area constrained by soil nutrient status with optimality principles

Wenjia Cai, Imperial College London, United Kingdom
*Email: w.cai17@imperial.ac.uk*
IIASA Mentor: Oskar Franklin (BNR) and Jaideep Joshi (ASA)

**Introduction.** Leaf area is the primary locus of mass and energy exchange. The ability of plants carbon acquisition and water transpiration is quantified by vegetation leaf area (amount of leaf). Therefore, leaf area is a key determinant of accurate characterization of many of plant biophysical and biochemical processes and affect our projection of vegetation response under climate change. Plant investments on leaf photosynthesis not only consist of leaf construction and maintenance cost, but also that for fine roots to acquire nutrient which is the source of chlorophyll. Soil nutrient is thus a critical factor in determining both overall and relative carbon allocation to leaf and root. Despite numerous studies on nutrient impact on leaf traits, few of them focused on leaf area. Based on eco-evolutionary optimality principles, we hypothesized that the ratio of fine roots biomass to leaf area would shift along the nutrient gradient to optimize net carbon gain, and the overall investments of leaf and fine root would be linked to soil nutrient status.

**Methodology.** With meta-analysis ('metafor' R package), we first investigate the how the ratio of fine root biomass and leaf area (hereafter fine root leaf ratio) change within one stand when soil nutrient increase using dataset on fertilization experiments across the globe. We then applied an IIASA-adapted metrics to quantify soil nutrient status in at sites in Europe and compared fine root leaf ratio across these sites with different soil nutrient status. These sites were further divided into groups with different phenology (evergreen or deciduous) for comparison. Finally using leaf and root costs as the function of soil nutrient status, we predicted vegetation greenness cover (fAPAR) at these sites using a vegetation productivity model and a newly developed leaf area framework and compared against Copernicus remotely sensed fAPAR product.

**Results.** Within same stand, increasing soil nutrients induce an allocation shift towards leaf area. Across sites in Europe, we also found similar pattern of decreasing fine root leaf ratio along the soil nutrients gradient. However, when separating into phenology groups, evergreen and deciduous trees had contrasting trends along nutrient gradient, with decreasing fine root leaf ratio for evergreen species and increasing ratio for deciduous species. By including soil nutrient status our explanatory power of leaf area prediction nearly doubled, increasing from 22% to 38%.




**Conclusions.** By using robust statistical analysis and simulation, our research suggested that soil nutrient affects the relative carbon allocation to leaf and roots, and that taking soil nutrient status into account can significantly improve the prediction of leaf area. Our findings also indicated that species with different phenology might respond differently to nutrient change and should be considered in future modelling.

# Spatial prioritization of conservation and restoration measures to meet 2030 biodiversity targets in the EU

Melissa Chapman, University of California Berkeley, USA
*Email: mchapman@berkeley.edu*
IIASA Mentors: Piero Visconti (BNR) and Martin Jung (BNR)

**Introduction.** In alignment with the global ambition to slow biodiversity loss through a comprehensive package of threat mitigation actions, the European Union has committed to ambitious conservation and restoration targets. These area-based targets ultimately seek to meet multiple ecological and ecosystem service objectives (e.g., both biodiversity conservation and climate mitigation), while ensuring sufficient agricultural production in EU Member states. Effectively meeting these commitments will require systematic planning that considers the spatial synergies between competing objectives and actions, and the complementarity of contributions of restoration and conservation to those objectives. Moreover, designing effective policy strategies to meet conservation and restoration targets will require assessments of different scenarios of burden sharing between EU Member states.

**Methodology.** Using multi-objective linear programming we spatially optimize the allocation of restoration and conservation measures across different land-cover types in the EU to achieve species conservation and carbon sequestration targets. We constrain this optimization problem using projected crop, pasture, and forest production estimates for the year 2030 and area-based conservation and restoration targets (20% of land). We explore different solution scenarios, both varying weightings of objectives and their policy implementation (EU vs. Member State targets) to understand interacting effects, synergies and tradeoffs between priorities and policy (Fig 1A)

**Results.** Optimizing conservation and restoration strategies to meet EU policy pledges within Member states increases expected carbon and biodiversity shortfalls (Fig 1A) when compared to allowing restoration efforts to be distributed free of constraints within the EU. We find relatively linear tradeoff frontiers between biodiversity and carbon mitigation targets, suggesting there may not be a clear "win-win" solution, but complex tradeoffs among objectives.

**Conclusions.** We show that integrating policy structures, like burden sharing, into conservation prioritization is critical for understanding the implications of those structures on expected conservation outcomes as well as proposing actionable solutions. Moreover, we find that simultaneously considering the allocation of multiple interacting conservation measures (restoration and protection) alongside livelihood needs (production) can significantly improve the efficacy and coherence of area-based efforts to address biodiversity loss.

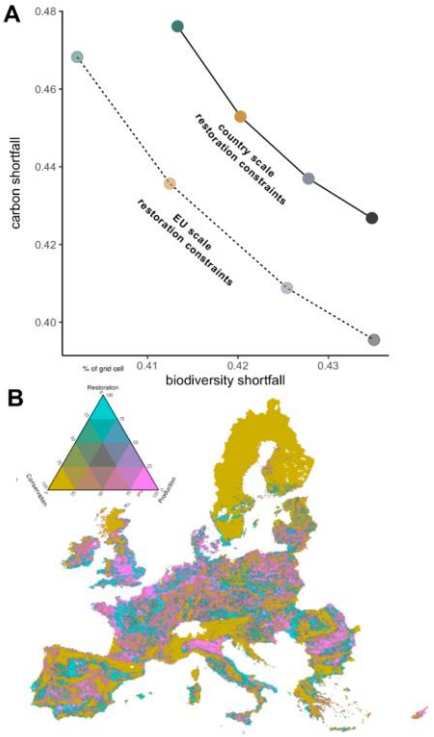



**Fig 1: (A)** We assess how burden sharing of ecosystem restoration impacts the tradeoff frontier between climate mitigation and species conservation targets and their relative shortfalls **(B)** Visualization of the spatial distribution of conservation, restoration, and production priorities across ecosystems.

# Apply deep learning based hydrologic models to rainfall runoff simulation at the global scale

Dapeng Feng, Penn State University, USA
*Email: duf328@psu.edu*
IIASA Mentor: Jens de Bruijn (BNR) and Reetik Kumar Sahu (BNR)

**Introduction.** Accurate hydrologic modelling is vital to characterize the natural water cycle and mitigate the impacts of climate change. Deep learning (DL) based models have achieved outstanding performance in rainfall-runoff modelling. However, previous studies were mainly performed at continental or smaller scales. In this study, we built both pure DL models and hybrid DL and physical models for modelling the global catchments covering different climate groups and comprehensively evaluated the performance of different models under various scenarios. We also discussed the benefits of integrating physical constraints with DL models.

**Methodology.** A global dataset including meteorological forcings, discharge observations and basin attributes in 4229 headwater catchments was used to run the simulations. We compared two different types of DL-based models. The first is a pure data-driven hydrologic model using the long short-term memory (LSTM) network, while the second is based on the differentiable parameter learning (dPL) framework which uses a physical model (HBV here) as the backbone and integrates it with the neural networks. We designed different types of benchmark experiments for global modelling including testing temporal generalizability (train and test models in different time periods) and spatial generalizability (train and test models in different regions).

**Results.** Both the LSTM and dPL models achieve promising performance for global hydrologic modelling in temporal generalization. The LSTM model gets KGE median of 0.73 for 4229 catchments, while the dPL model with multi-component and static parameters achieves KGE median of 0.68. With dynamic parameterization, the dPL model can further narrow the gap and approach the LSTM performance. Both models perform best in catchments of the temperate climate group while worst in those of the arid climate group. For the difficult cross-continent prediction problem which tests the spatial extrapolation, the performance of all the models deteriorates a lot, however, dPL models with physical constraints show advantages over the pure data-driven LSTM model.

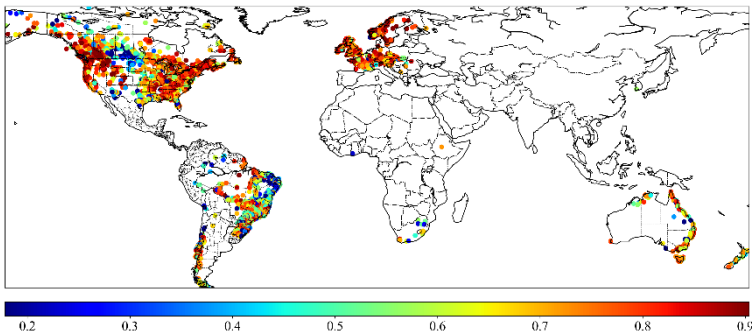



*Figure 6 The location of 4229 catchments and KGE performance of the LSTM model.*

**Conclusions.** DL based models are promising for the hydrologic modelling at the global scale, achieving high performance for the in-sample prediction. We also demonstrate the potential risk of the pure data-driven models for spatial extrapolation. With evolved structure and advanced parameter regionalization under the dPL framework, differentiable models with physical constraints show great power for the prediction in large ungauged regions globally.

## References

Feng, D., Fang, K., & Shen, C. (2020). Enhancing streamflow forecast and extracting insights using long-short term memory networks with data integration at continental scales. Water Resources Research, 56(9), e2019WR026793.
Tsai, W. P., Feng, D., Pan, M., Beck, H., Lawson, K., Yang, Y., Liu, J. & Shen, C. (2021). From calibration to parameter learning: Harnessing the scaling effects of big data in geoscientific modeling. Nature communications, 12(1), 1-13.
Beck, H. E., Pan, M., Lin, P., Seibert, J., van Dijk, A. I., & Wood, E. F. (2020). Global fully distributed parameter regionalization based on observed streamflow from 4,229 headwater catchments. Journal of Geophysical Research: Atmospheres, 125(17), e2019JD031485.

# The integration of biodiversity in preferential trade agreements. A text as data approach to the adaptability of polycentric trade governance

Simon Happersberger, Vrije Universiteit Brussel, Belgium
*Email: Simon.happersberger@vub.be*
IIASA mentor: David Leclère (BNR) and Nadejda Komendantova (ASA)

**Introduction.**
International trade embodies large amounts of biodiversity pressure through species invasions, and through habitat loss caused by telecoupled consumption. Although trade governance is a key indirect factor for these trends, it has remained understudied how Preferential Trade Agreements (PTA) have adapted to declining global biodiversity. PTAs might evolve towards polycentricity through the participation of stakeholders (Ostrom 2010), or nonlinearly create legal innovations as complex adaptive system (Morin et al. 2017), or react to the interferences of telecoupling in socio-ecological systems (Biggs et al 2021). To assess the coverage of biodiversity and participation, we apply a text-as-data approach to the full-text corpus of 446 PTAs (1948-2016) from the Text of Trade Agreements project.

**Methodology.**
We construct two dictionaries on biodiversity and on participation with 425 and 288 keywords derived from the literature and from bibliometric data from Scopus. The biodiversity dictionary is organized in biodiversity components, drivers of biodiversity loss, and biodiversity governance. The participation dictionary corresponds to three levels of Arnstein's ladder of Participation (1969), nonparticipation, tokenism, and citizen power. The analysis of keyword frequencies, dynamics and co-occurences is conducted with the R package quanteda based on 4-grams.

**Results.**
PTAs have increasingly integrated biodiversity keywords since 1997. Ecosystems (29%) were the most important category from 1948 until 2008, when they were replaced by species (28%). Among the drivers, exploitation (14 %) has been the focal point since 1948, however land-use change (7%) has risen rapidly since 1995. Biodiversity policies are mentioned increasingly since 2000 but have lost in relative importance since 1995. Genes, climate change, biological invasions, and agreements are all rarely mentioned. PTAs have also become more participatory over time, but non-participation was replaced mainly by tokenism. Citizen power has only minimally increased since 1948. Traditional knowledge, local communities, and biological diversity cooccur as separate subcommunity.

**Conclusions.**
PTAs have adapted only to a limited extent to declining global biodiversity. Biodiversity keywords have slightly increased and shifted focus from ecosystems to species, and from exploitation to land-use change but we do not observe a phase shift: biodiversity governance seems still to be a separate rather than an integral part of PTAs. Participation has increased in terms of tokenism, whereas citizen power has remained low for over 60 years. Future work can analyse geographical patterns around biodiversity hotspots and include data on trade and biodiversity.

**References**
ARNSTEIN, Sherry (1969). A ladder of citizen participation. Journal of the American Institute of planners 35: 216-224.
MORIN, Jean Frédéric et al. (2017). The trade regime as a complex adaptive system. Journal of International Economic Law: 20, 365-390.
OSTROM, Elinor (2010). Beyond markets and states. American Economic Review 100: 641-72.
BIGGS, Reinette, et al. The Routledge handbook of research methods for social-ecological systems. Taylor & Francis, 2021

# Global system archetypes for addressing groundwater sustainability challenges and opportunities

Xander Huggins, University of Victoria, Canada
*Email: xanderhuggins@uvic.ca*
IIASA Mentor: Taher Kahil (BNR) and Amanda Palazzo (BNR)

**Introduction**. Groundwater provides critical services that underpin a broad set of ecological processes, Earth system dynamics, and social goals. Yet, over half of the major aquifers of the world are in states of depletion and global action is needed to advance groundwater sustainability to maintain these services.[1,2] While global action is often called for,[3] the need for groundwater sustainability strategies to be attuned to local biophysical and social context is under-emphasized in the global scale literature. Many typologies of groundwater systems exist,[4-6] however all to date only consider physiographic attributes of groundwater systems. Arguably, a typology based on groundwater system *interactions* would be more relevant for developing groundwater sustainability strategies. Here, we derive a global typology of groundwater systems based on their interactions with social, ecological, and Earth systems, and call these functionally distinct systems *groundwater system archetypes.*

**Methodology.** Conceptually, we simplify the complex network of groundwater interactions into seven social (S) and biophysical (B) interactions: climate (B), streamflow (B), wetlands (B), irrigation (S), economic value (S), access equality (S), and integrated management (S). Using best-available global data sets representing each interaction, we perform cluster analysis to identify archetypes. We employ multiple clustering algorithms and attribute archetype membership based on agreement across algorithms after reclassification to create "comparable maps".[7] We conclude with an assessment of challenges and future opportunities by summarizing groundwater depletion rates, hydropolitical risk, population growth, and agricultural intensification potential within archetypes.

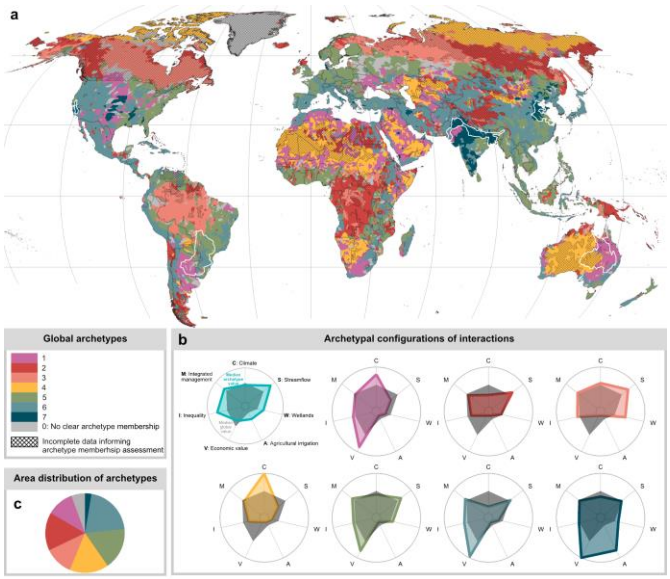



**Figure 1**: (a) Map of global groundwater system archetypes. (b) System interactions for each archetype. (c) Archetype area distribution.

**Results**. Seven archetypes of groundwater interactions with social-ecological systems are identified (Fig.1). Had each system interaction been classified individually, the global data space would yield a set of nearly 500 unique (over-specified) configurations. This 70x reduction in system types afforded by clustering is necessary for guiding action at regional to global scales.[8] Archetypes are validated by evaluating agreement with unique system types. As 85% of unique systems are classified along archetype classes, the system simplification afforded through clustering retains broad trends in groundwater interactions.

**Conclusions**. This work presents a new, complex systems-, and function-oriented conceptualization of global groundwater. The archetypes present an initial framework that could facilitate the development of regionalized networks to generate and share sustainable groundwater solutions within archetypes and highlight important system differences when working across archetypes. As more data are collected, and at increasingly higher resolutions, potential exists for future work to consider multi-scale derivations of archetypes and trajectories of archetype membership based on various development scenarios.

**References**

1 Richey, S. et al. *Water Resour. Res.* (2015).
2 Famiglietti, J. *Nat. Clim. Change.* (2014).
3 Gleeson, T. et al. *Nature*. (2019).
4 Richts, A. et al. Sustaining Groundwater Resources. (2011).
5 Margat, J., and Van der Gun, J. Groundwater around the world: a geographic synopsis. (2013).
6 Reinecke, R. et al. *Hydrol. Earth. Syst. Sci.* (2019).
7 Seitz, D. et al. *Glob. Environ. Change*. (2011).
8 Oberlack, C. et al. *Ecol. Soc.* (2019).

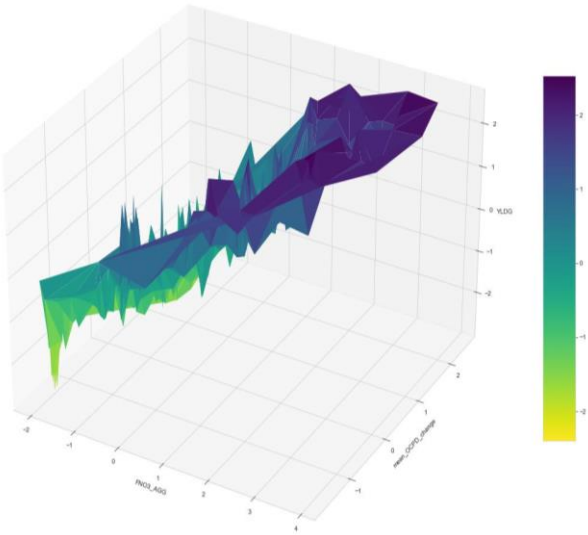
# Investigating the biophysical determinants of SOC response to management

Tara Ippolito, University of Colorado Boulder, United States
*Email: Tara.Ippolito@colorado.edu*
IIASA Mentors: Juraj Balkovic (BNR) and Tamas Krisztin (BNR)

**Introduction.** The management of Soil Organic Carbon (SOC) is a critical component of both climate change mitigation and global food security. Agriculture has contributed substantially to a reduction in SOC through cultivation, thus there has been renewed focus on management practices which minimize this reduction in SOC as a pathway towards reducing greenhouse gas emissions. Investigating the biophysical response relationships between changes in SOC and management variables is critical to understanding the anticipated effect of management on SOC.

**Methodology.** Across 88,000 unique spatial simulation units across Europe, we use multifactorial crop simulations from the Environmental Policy Integrated Climate (EPIC) model to investigate the response relationships between SOC and management and climate variables. We split simulation units into subgroups by climate cluster and soil texture, in order to compare response relationships between biophysically distinct growing conditions. Within each of these subgroups, we build a subgroup-specific ensemble of multiple polynomial regression meta-models to predict the 40-year mean in annual change in SOC. From this ensemble, we explore the ways that management and climate variables interact with changes in SOC and how these interactions differ among subgroups. Furthermore, we investigate the relationships between management and climate variables and long-term yield to identify synergies and trade-offs between increasing SOC and increasing yield.

**Results.** Through this analysis, we find notable differences in the response relationships between change in SOC and management and climate variables which are dependent on the biophysical characteristics of the site. Our multiple polynomial regression meta-model is highly accurate in predicting long-term mean change in SOC, long-term mean in yield, long-term standard deviation of change in SOC and long-term standard deviation in yield (r-squared .99, .98, .97, .90, respectively). Through a leave-one-out feature importance analysis, we find that the carbon content of applied residues is the most important variable in predicting long-term changes in SOC. For predicting long-term yield, we find that applied nitrate fertiliser is the most important variable. The relationships between management variables such as applied nitrate fertiliser and mean change in SOC vary substantially by biophysical subgroup; these differences have implications for the trade-offs between optimising SOC and yield.



**Conclusions.** Through the use of an ensemble of multiple polynomial regression models, we have built an interpretable meta-model of the EPIC model which allows us to identify important drivers of yield and changes in SOC. We find distinct response relationships between change in SOC and management and climate variables which depend on the biophysical characteristics of the simulation units. This dependency is highly relevant to decision-makers who aim to optimize both crop yield and SOC storage.

# Optimization of the IIASA's FLAM model to represent forest fires in South Korea

Hyun-Woo Jo, Korea University, South Korea
*Email: endeavor4a1@gmail.com*
IIASA Mentor: Andrey Krasovskiy (BNR) and Florian Kraxner (BNR)

**Introduction.** Global risk of forest fires is amplified by the climate change driven heat waves, leading to more intensive biomass burning, which create a vicious cycle by accelerating the climate change. Despite of the growing risk of forest fires, a response system in South Korea, where more than 60% of its land is forest, is still focusing on posterior measures. To improve preventive measures, forest fire model needs to be developed for assessment of future risks of forest fires and burned areas.

**Methodology.** This study aims at optimization of the IIASA's FLAM – a processed based model integrating both biophysical and human impact – to the environment of South Korea for projecting the pattern and scale of future forest fires. The following model developments were performed in the study: 1) optimization of probability algorithms in FLAM, including ignition probabilities conditional on population density, lightning frequency, and fuel taking into account distance to cropland, based on the national GIS data downscaled to $1km^2$, and 2) improvement of soil moisture computation by adjusting Fine Fuel Moisture Code (FFMC) used by FLAM to represent feedbacks with vegetation; this was done by fitting soil moisture to the daily remote sensing data, 3) deeper look at the fire frequency in addition to areas burned simulated by FLAM.

**Results.** Our results show that modelling the seasonal pattern of forest fire in Korea – frequent fire in dry spring and sparse fire in wet summer – was considerably improved by the optimization. The length of forest boundary neighbouring the agricultural field was introduced in the model as an ignition factor since burning agricultural waste is one of the greatest ignition sources during springtime. Also, the probability of ignition by lightning was adjusted from monthly to daily computation to avoid seasonal overestimation of ignitions at frequent lightning events during rainy summer. Moreover, adjusting the FFMC computation based on remotely sensed soil moisture index helped adjusting the rate of soil moisture change in South Korea that happens to be much slower for sparse vegetation, which is in line with the literature (Hu *et. Al.*, 2019; Yang *et. Al.*, 2019). The Pearson coefficient for fire frequency between monthly predictions by the optimized FLAM and observations from national statistics was improved from 0.171 to 0.854.

**Conclusions.** Even though FLAM already contained main algorithms for interpreting biophysical and human impact on forest fire at a global scale, they were applicable to South Korea only after optimization of all its modules. The improved process for interpreting ignition source and soil moisture indicates that there are extreme risks of forest fires during dry spring season in South Korea. Furthermore, dense population in urbanized areas of South Korea in combination with other factors lead to exponentially increasing ignition probabilities. As the optimization succeed to reproduce the regional specific pattern of forest fire, it would be followed by the research for developing adaptation strategies corresponding to the projected future risks.

## References

Hu, J., Lü, D., Sun, F., Lü, Y., Chen, Y., & Zhou, Q. (2019). Soil Hydrothermal Characteristics among Three Typical Vegetation Types: An Eco-Hydrological Analysis in the Qilian Mountains, China. Water, 11(6), 1277.
Yang, W., Wang, Y., He, C., Tan, X., & Han, Z. (2019). Soil water content and temperature dynamics under grassland degradation: a multi-depth continuous measurement from the agricultural pastoral ecotone in Northwest China. Sustainability, 11(15), 4188.

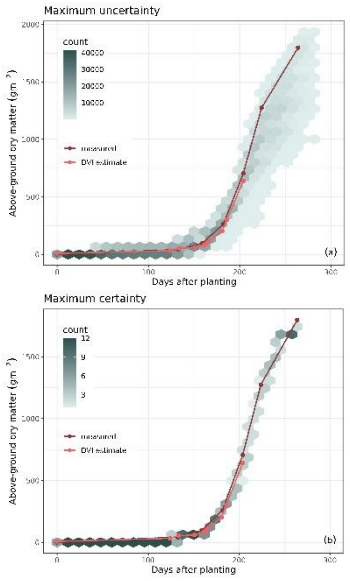
# Soil data requirements to improve local fertilization strategies – and how to get there

Marlene Palka, University of Natural Resources and Life Sciences Vienna, Austria
*Email: marlene.palka@boku.ac.at*
IIASA Mentor: Rastislav Skalský (BNR) and Juan Carlos Laso Bayas (ASA)

**Introduction.** Agricultural management practices largely rely on empirical approaches reflecting farmers' experiences from past years. These empirical decisions are afflicted with uncertainty due to incomplete knowledge of the complex crop-environment-management interactions. In the face of climate change, these complexities are expected to become more adverse, leaving empirical management at risk for failure. With this study, we want to contribute to the development of an agricultural decision support system that facilitates current crop management to be more resource efficient and reduce GHG emissions from agriculture. We focus on synthetic nitrogen (N) fertilization as an application case of this tool and integrate a process-based crop model and model input data from different sources and of different availability as a prototype of a potential support tool. We ask how coarse/specific certain input needs to be, and how to attain this level of information, when only little output uncertainty is tolerable for a local management improvement.

**Methodology.** We created a multifactorial simulation experiment using a simple simulation model for winter wheat in Eastern Austria as a case study region. The model was calibrated to meet local growing conditions in previous studies. Considering five integral model inputs (soil hydrological parameters, soil water content at sowing, mineral N content at sowing, sowing date, and amount of fertilizer applied), and introducing 3-4 scenarios of uncertainty per input, we generated a total number of 13, 824 daily simulation runs. We analysed the simulated output against data collected both destructively and non-destructively from Sentinel-2 images from four field experiments within our study region.

**Results.** In general, the simulated outcome of our proposed support tool frames seasonal crop measurements at all experimental sites. In the space of maximum uncertainty (top figure, for one selected site), this comes at the expense of large outcome variability (RMSE=219.44 $gm^{-2}$), however. Some model inputs, especially those not directly related to management (soil hydrological properties and water content at sowing) are most important for locally accurate simulation outcomes, while management inputs such as sowing date and the fertilizer amount play a minor. This shows that non-management related uncertainties might in fact mask potential benefits of refined management practices when providing management support via a tool similar to our prototype. Ultimately, for a scenario of maximum certainty (bottom figure) we were able to minimize uncertainty and simulate measured crop growth well over the entire season (RMSE=43.48 $gm^{-2}$), an essential first step towards local fertilization improvements.




**Conclusions.** After reducing data uncertainty, we were able to create results potentially relevant for local fertilization improvements. One cost-efficient way to achieve this reduction in uncertainty would be a targeted involvement of users within our system. From a farmer's perspective, information on sowing date or fertilizer amount could be easily supplied at no additional expense. The uncertainty of other inputs related to hydrological properties or water content could be narrowed using simple field tests.

# Global trade and socio-economic and environmental trade-offs in Indonesia: A study on the future of Indonesian palm oil

Irlan A. Rum, Leiden University, The Netherlands
*Email: i.a.rum@cml.leidenuniv.nl*
IIASA Mentor: David Leclère (BNR) and Esther Boere (BNR)

**Introduction**. Indonesian palm oil production has doubled in the last decade, driven by increasing consumption at national and global scales. Oil palm plantations are primarily associated with cropland expansion in Indonesia, leading to large biodiversity loss and greenhouse gas emissions. This exemplifies recent trends in domestic resource exploitation in tropical countries for global markets, with domestic socio-economic improvements but detrimental climate and biodiversity consequences. Models and scenarios are often used to investigate potential future developments and options to mitigate these trade-offs, yet to date no model is able to adequately cover most relevant dynamic processes across spatial scales (from global to local) and disciplines (socio-economic vs environmental aspects). In this study, we develop a coupling method to inform socio-economic and environmental aspects while covering global (e.g., trade) to local (e.g., land use and employment) interdependencies. We link a regional version of the GLOBIOM partial equilibrium model of the agriculture, forestry and bioenergy sectors (a gridded global model covering trade dynamics in the oil palm sector and refined for Indonesia) to the regional MSRIO input output model (an EXIOBASE derived global IO model extended with subnational detail on supply chains in Indonesia and related employment) and apply the modeling framework to explore future scenarios for the oil palm sector in Indonesia.

**Methodology**. GLOBIOM can model future dynamics in demand, trade and production for regional to global agricultural sectors, while MSRIO can model present-day interdependencies between all economic sectors and their input use, including value added and employment. We link the changes outputs of global consumption and trade of oil palm crop simulated by GLOBIOM between 2010 and 2030 under various scenarios as inputs to shock the domestic consumption and export of all regions in MSRIO. We then compare MSRIO outputs to those of the baseline year 2010. We focus on regional Indonesia, measuring the change in regional output (by sector), value added (by sector and input factors), employment (by sector and skill labors), and land use (by sector and land use types). Finally, we extended the MSRIO model by adding an estimate of potential species loss for each taxon from land use change, using characterization factors developed for life cycle assessment.

**Results**. Preliminary results based on a stylized scenario representing a prolongation of historical trends (10% increase in global demand every 5 years from 2010 to 2030) is used to demonstrate the coupling. Within Indonesia, impact differ across provinces, with Sumatra and Kalimantan islands have the highest positive impact both on regional GDP and employment. We identify that Riau and North Sumatra provinces experience negative impacts on land use as they require more inputs on land use. The Sumatra lowland rain forest has the highest potential for species loss on all taxonomic groups.

**Conclusion**. This study proposes a coupling method to link a global spatial equilibrium model with a global MRIO model with subnational resolution in Indonesia. We were able to analyze the impact of global demand and trade between multiple countries, which then trickled down to local provinces and ecoregions in Indonesia. Further steps include (1) checking consistency between models in simulated land use change, (2) linking land productivity on land use between models, (2) designing new scenarios exploring the impact of global trade and domestic policies.

# Obesity/overweight and environmental impacts: Assessment of excessive food intake in China

Zhimin Shi, Beijing Normal University, China
*Email: shizhimin@mail.bnu.edu.cn*
IIASA Mentor: Marta Kozicka (BNR) and Michael Kuhn (EF)

**Introduction.** Rapidly rising incomes and increased urbanization are driving a global dietary transition, which is closely related to environmental and human health. In such cases, global agriculture and food production release more than 25% of all greenhouse gases, occupy about 40% of global land and utilize over 70% of freshwater. Much in synchrony with the worldwide transition, the dietary changes in China and the resulting rise in body mass index also caused many problems. Currently, 6.4% of Chinese adults are obese and 34.3% are overweight. Excess food intake is considered the fundamental cause of obesity and overweight, while it will amplify the burden on the natural environment and climate change. The environmental impacts of diet and the negative health consequence of excessive food intake are well acknowledged as a global issue, yet the environmental implications of excessive food have been less well studied.

**Methodology.** Combing the metabolism process and diet guidelines and using micro-scale data, this study aims to investigate the impact of excessive food intake on national sustainability. In detail, the Life cycle assessment (LCA) method has been used to provide a comprehensive estimation of the environmental impact resulting from excessive food intake in China. The system boundary of LCA consists of the full stages of "farm-to-plate," including agricultural production, processing, distribution, and cooking.

**Results.** The diet structure of Chinese residents is significantly characterized by a high proportion of cereals, vegetables and meats. It was detected that the diet of overweight and obese people deviated more from the dietary Guidelines than that of normal weight people. On a population level, excessive energy intake accounts for 39.80 trillion kcal for the Chinese residents in overweight and obesity groups in one year. The excess food intake for one year is 11.70 Mt, resulting in a corresponding additional environmental burden of 37,542 Mt $CO_2$ eq.

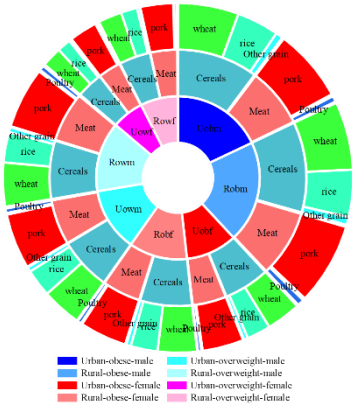



Fig.1 The carbon footprint of excessive food intake in China

**Conclusions.** According to the study, excessive food intake has already been a big issue, causing a large additional environmental footprint. It is important to note that this is a static analysis of current diets and that this trend is expected to continue in the future. It is therefore important to assess the potential impact of future diets. The next step in this study intends to assess the impact of future excessive food intake by using GLOBIOM.

# Irrigation as an adaptation measure to climate change in US agriculture

Christopher M. Wade, North Carolina State University, United States
*Email: cmwade2@ncsu.edu*
IIASA Mentors: Tomás Kriszten (BNR) and Stefan Frank (BNR)

**Introduction.** The net impacts of climate change on global agriculture are uncertain, due to confounding effects such as elevated levels of atmospheric carbon, increased temperatures resulting in higher evapotranspiration demands, increased variability in precipitation, and increasing events of severe weather [1]. Increasing the amount of irrigation being applied to crops can compensate for increased evapotranspiration demand, reduce heat stress, and accelerate phenological processes [2], [3], possibly reducing the negative impacts from a warming climate. In the United States, irrigated area has remained relatively constant over the past two decades, while irrigation intensity has declined as irrigation technology has improved, crop mixes have changed, and shifts in where irrigation is occurring [4].

**Methodology.** To project the impacts of climate change on US agriculture and assess irrigation as an adaptation measure, an updated version of the Global Biosphere Management Model (GLOBIOM) has been developed to include climate change projections on the global forestry and agriculture sectors [5], [6]. GLOBIOM is a detailed partial equilibrium model of the global agriculture and forestry sectors and is designed to optimize land use decisions to maximize producer and consumer surplus. For this analysis, the US agricultural sector has been updated to reflect recent historical amounts of area irrigated for major crops.

**Results**. Production of major crop commodities in the US (corn, wheat, and soybeans) is projected to increase relative to the baseline in all but the most pessimistic modeling scenarios. It is also shown that under climate change, demand for irrigated agriculture area increases, while irrigation intensity continues historical trends and declines. Under RCP8.5 irrigation water consumption from 2020 to 2060 increases by 3.3% to 5.5% relative to a stable climate scenario, while irrigated area increases by 23.8% to 47.8%.

**Conclusions.** We find that the US agricultural sector will shift under climate change, with increasing temperatures causing a northern shift in crop production which may allow the US to expand production relative to a stable climate scenario. However, irrigation water demands will also increase as evapotranspiration requirements rise. We project that both a spatial shift, away from the central US and towards the southeast and northwest, and an increase in irrigation water consumed will allow the US to increase its agriculture commodity production relative to a stable climate future.

## References

[1] Tubiello, F. N., & Fischer, G. (2007). Reducing climate change impacts on agriculture: Global and regional effects of mitigation, 2000–2080. *Technological Forecasting and Social Change*, *74*(7), 1030-1056.
[2] Minoli, S., Müller, C., Elliott, J., Ruane, A. C., Jägermeyr, J., Zabel, F., ... & Pugh, T. A. (2019). Global response patterns of major rainfed crops to adaptation by maintaining current growing periods and irrigation. *Earth's Future*, *7*(12), 1464-1480.
[3] Tack, J., Barkley, A., & Hendricks, N. (2017). Irrigation offsets wheat yield reductions from warming temperatures. *Environmental Research Letters*, *12*(11), 114027.
[4] Hrozencik, R. Aaron and Marcel Aillery. December 2021. Trends in U.S. Irrigated Agriculture:
Increasing Resilience Under Water Supply Scarcity, EIB-229, U.S. Department of Agriculture,
Economic Research Service.
[5] Havlík, P., Schneider, U. A., Schmid, E., Böttcher, H., Fritz, S., Skalský, R., ... & Obersteiner, M. (2011). Global land-use implications of first and second generation biofuel targets. *Energy policy*, *39*(10), 5690-5702.
[6] Baker, J. S., Havlík, P., Beach, R., Leclère, D., Schmid, E., Valin, H., ... & McFarland, J. (2018). Evaluating the effects of climate change on US agricultural systems: sensitivity to regional impact and trade expansion scenarios. *Environmental Research Letters*, *13*(6), 064019.

# A novel integrated hydro-economic model based on the societal water cycle framework: application to water stress assessment in China

Dan Wang, University of Groningen, Netherlands
*Email: dan.wang@rug.nl*
IIASA Mentors: Taher Kahil (BNR) and Reetik Kumar Sahu (BNR)

**Introduction.** Human activities are significant drivers for water quantity and quality related stress. Understanding the impacts of human activities on water resources is an important scientific and practical question. Numerous articles have mainly considered the impact of water withdrawal or virtual water trade on water resources and have ignored the impacts on water quality and other processes of the societal water cycle, which include processes like water leakage, water consumption, direct wastewater discharge, wastewater treatment, wastewater reclamation and agricultural return flow. Based on the framework of societal water cycle, we develop a hydro-economic model to track physical and virtual water quantity and quality metabolism and to study the impacts of human activities on water quantity and quality stress in China.

**Methodology.** We use material flow analysis and mass balance methods to trace the physical water and pollutant flows across various process in the societal water cycle. A Multi-Regional Input-Output (MRIO) model is adopted to track the imported and exported virtual water leakages, virtual water consumption, different virtual return flows and four water pollutants (chemical oxygen demand, ammonia nitrogen, total nitrogen and phosphorus) flows. This model is implemented at a provincial level in China covering 31 provinces and incorporating 29 different economic sectors within each province. Water stress measurements are used to evaluate water quantity or quality stress.

**Results.** In China, 25 out of 31 provinces suffered from water quantity stress and 29 provinces experienced serious water quality stress in 2017. Water quantity stress accounts for 4-26% of total water stress (the sum of quantity and quality stress), and this percentage is 74-96% for pollution induced stress. Agriculture is the most polluting sector, since agricultural pollution contributes to 20-85% of total water stress, while this value is only 0.3-7.2% for industrial pollution. Physical water quantity flows show that water leakage accounts for 7-24% of water withdrawal, water consumption accounts for 43-73%, total return flow (sum of agricultural water return flow, direct wastewater discharge and wastewater treatment) varies from 20-50%. It indicates that there is a great potential to conserve water to reduce water leakage and return flow, and then to mitigate water quantity stress in China. Virtual water quantity flows present that exported water consumption accounts for 42-77% of total exported water withdrawal, while exported virtual agricultural return flows range from 1.4% to 79%, exported virtual water loss is 0.1-10.3%, and other exported virtual water return flow account for 0.8-3%. Virtual water quantity trade results reflect that exported return flow account for a large proportion, which aggravates the water quantity stress. Water pollutant flows indicate that agricultural sector is the largest pollutants emitter for most provinces, while household rank the second, and industrial sectors contribute the least. Virtual pollutant flows indicate that some stressed provinces alleviate water quality stress by outsourcing pollutants to other regions, while some exacerbate water quality stress by more export. Physical and virtual water quantity and quality metabolism analysis present a novel way to analyse the impact of human activities on water stress and is also a useful tool to analyse the pathway to reduce water stress for each region. Our analysis shows a wide variability in the contribution of water stress from different sectors. Therefore, it is undesirable to generate and implement a one-size-fits-all water stress mitigation strategy for all provinces in China. A more province specific strategy needs to be designed.

**Conclusions.** China is a water stressed country. Majority of the provinces suffer from water quantity and quality stress simultaneously. There is however a large potential to conserve water and reduce water quantity stress by improving water use efficiency, as return flow accounts for 20-50% of water withdrawal. These return flows also contribute to serious water quality stress (74-96%), especially from the agricultural sector and households. For some stressed provinces, a lot of virtual return flow are exported, which aggravate local water stress. Return flow is a crucial factor that influence both water quantity and quality related stress and should be considered for policy implementation.

# *Energy, Climate, and Environment (ECE)*

# Air quality benefits from mitigation of Black Carbon emissions in Northern India

Prerita Agarwal, University of Edinburgh, United Kingdom
*Email: prerita.agarwal@ed.ac.uk*
IIASA Mentors: Pallav Purohit (ECE) and Zbigniew Klimont (ECE)

**Introduction.** Ambient air pollution is now recognised as India's highest health risk factor, with the population exposed to fine particulate matter $PM_{2.5}$ (mean diameter <2.5 microns) levels exceeding WHO Air Quality Guidelines. Black Carbon (BC) particles released from incomplete combustion of carbon-based fuels are a strongly light-absorbing component of $PM_{2.5}$. BC emissions from India are among the highest globally, impacting regional climate and human health. Therefore, control of BC emissions offers a potentially large scope for achieving co-benefits for climate and public health. In addition, North India frequently suffers from extreme seasonal haze pollution. However, a complete understanding of the role of BC in amplifying pollution is still lacking. We look at future BC emissions reductions from a policymaking context and potential co-benefits in mitigating severe haze pollution.

**Methodology.** We compare alternate policy scenarios using the GAINS model framework with the baseline or current legislation scenario (with 2018 as the base year) with current and planned levels of enforcement of air pollution control measures/policies. The alternative scenarios include maximum technically feasible reductions (MTFR), Net-Zero emissions (NZE) and Sustainable Development (SDS) scenarios with MTFR controls. As a next step, we use the online atmospheric chemistry transport model (WRF-Chem) to quantify the sensitivity of $PM_{2.5}$ to precursor BC emissions and understand the impact of various policy interventions on the overall $PM_{2.5}$ concentrations. Here, we first conduct an idealised sensitivity experiment using a perturbative approach to determine the changes in $PM_{2.5}$ concentrations in response to a reduction in BC emissions by 90% over the study domain for the months of October and November.

**Results.** In the baseline scenario, between 2018 to 2050, only a marginal reduction of $PM_{2.5}$ emissions (~11%) is projected, while BC emissions are reduced by ~53%. BC emissions show over 90% reduction from 2018 to 2050 in NZE and SDS scenarios. The residential sector is projected to contribute dominantly toward the decline in $PM_{2.5}$ and BC emissions by 2050. Non-exhaust emissions are expected to dominate the total BC emissions by 2050. Overall, the sensitivity of modelled $PM_{2.5}$ concentrations to changes in BC emissions shows a decline of 50% over the modelling domain. While, for some major cities in North India, the $PM_{2.5}$ concentrations show a sensitivity of up to 18 μg $m^{-3}$ (see Fig.1). The sensitivity case for a perturbed model run is an idealised scenario illustrating the models' potential for mitigation of $PM_{2.5}$ pollution due to BC emissions. Evaluation of $PM_{2.5}$ concentrations from base model run driven using GAINS emissions inventory show an $R^2$=0.72 and captures spatial variation well.

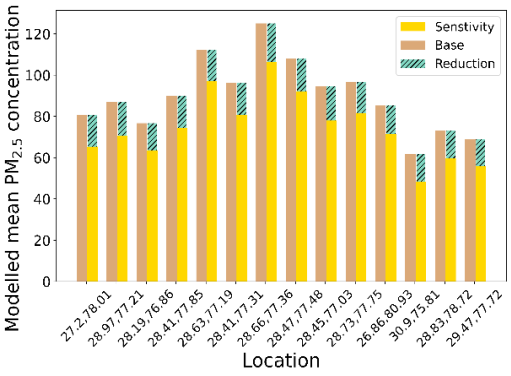



*Fig 1: $PM_{2.5}$ concentration changes in response to BC- emission reductions*

**Conclusions.** The current emissions control measures will be insufficient to reduce the high PM levels across India. Ambitious control measures like targeting multiple pollutants would efficiently mitigate co-emitted climate-relevant species like BC. Our idealised model run provides a better understanding of the maximum air quality benefits that would be achieved from BC emissions controls in policy strategies.

# Green transition pathways for the maritime industry – modeling interactions of behavioral and socioeconomic aspects of demand with alternative fueling options

Sebastian Franz, Technical University of Denmark (DTU), Denmark
*Email: semfr@dtu.dk*
IIASA Mentor: Paul Kishimoto (ECE)

**Introduction:**

Reducing greenhouse gas (GHG) emissions from the maritime sector will be a crucial component of climate mitigation toward meeting the Paris Agreement targets. Therefore it is essential to identify decarbonization pathways for the maritime industry that are feasible, efficient, and avoid carbon-intensive lock-in, while still supporting the movement of goods needed for human well-being. To study how these pathways may interact with broader socio-economic conditions, we developed an open-source maritime gravity demand model that incorporates a wide range of SSP-differentiated measures for an interdisciplinary set of phenomena, that enables maritime activity projections to vary in a complex manner with socio-economic and -cultural futures.

**Methodology:**

We begin with a large historical dataset on shipped goods and combine it with several interdisciplinary SSP-specific projections. The combined dataset allows us to draw a holistic picture differentiated across shipping market segments like oil, container, and bulk dry. Based on regression coefficients of historical data for the respective parameters, we extrapolate trade flows by multiplying them with future projections—drawn from recent literature—of the respective parameter. The used parameters are chosen carefully for the respective ship segment to improve the extrapolation (e.g., historical animal product demand and projections for the same are linked to trade flows on refrigerated vessels, but not others). This process yields trade flows in monetary units, which we then translate into cargo tonnage by mapping them with geo-spatial data of actual port calls in a base year. This method yields projected maritime demand for different ship types and SSPs. While rich in their own right, these projections will also be used (beyond the YSSP) to parametrize an improved version of the shipping representation in the MESSAGEix-GLOBIOM/MESSAGEix-Transport global integrated assessment model. The added detail in this model will allow it to cover demand/activity for maritime shipping of *all* commodities.

**Results:**

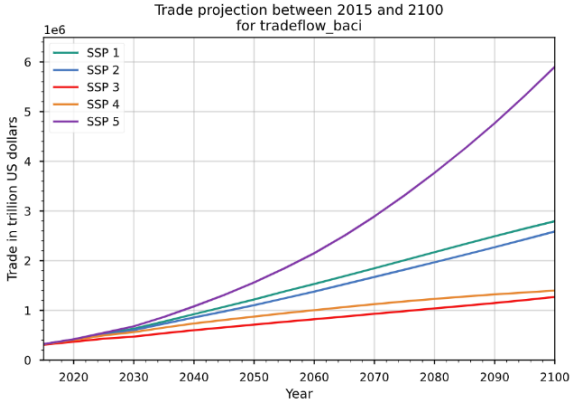



*Figure 7: Global trade projections for SSPs*

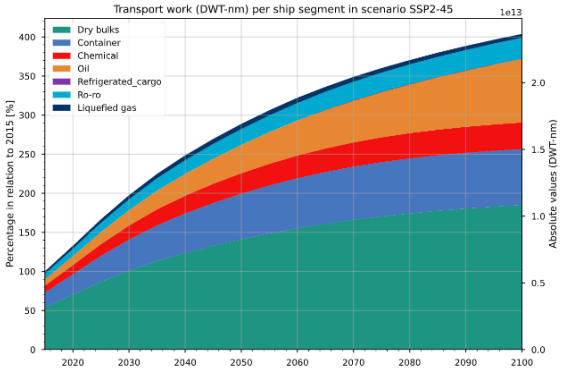



*Figure 8: Global maritime demand per ship segment for a SSP2-45 scenario*

**Conclusion:**

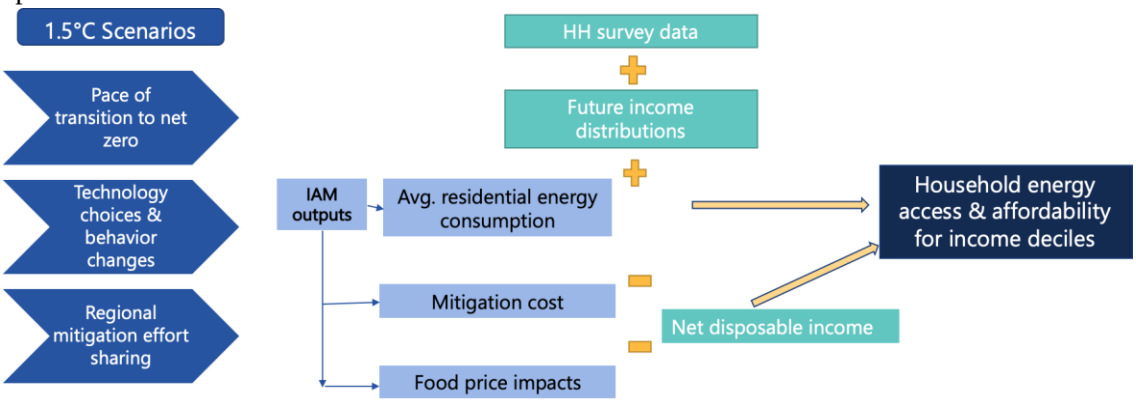
Results show vast differences in future maritime demand projection across both SSPs and countries. We project that developing countries will significantly increase maritime activity while that of industrialized countries will eventually saturate. The level of maritime activity in the future heavily depends on the chosen parameters for the respective ship segment and its future projections. Overall, the work demonstrates a successful combination of interdisciplinary datasets into one analysis yielding improved maritime demand projections and improved representation of SSP narratives, reflective of socio-economic factors usually omitted from sector-focused analyses.

# Distributional impacts of diverse 1.5ºC mitigation pathways on energy poverty

Mel George, University of Maryland – College Park, USA
*Email: georgemv@umd.edu*
IIASA Mentors: Shonali Pachauri (ECE), Narasimha Rao (ECE), and Jihoon Min (ECE)

**Introduction.** Can some mitigation pathways achieve both social and climate goals? Climate policies could transfer risks between communities, impose economic burdens on some sections, creating winners and losers. Even when targeting the same climate outcome, such transition risks could depend on the pace of change, technological choices and socioeconomic factors and imply dissimilar outcomes, spatially and by income strata. Analyzing distributional effects on vulnerable sections is important for enhancing national mitigation ambition by supporting social objectives. Filling a gap in the existing literature, we assess the impacts on national energy priorities and household energy burdens for diverse mitigation pathways to similar climate outcomes, in a consistent framework.

**Methodology.** We model 18 mitigation pathways varying by pace (net zero year), technology choices (renewables, carbon capture or nuclear, rapid electrification, behaviour change etc.) and global effort sharing (by capability, sovereignty, cost optimality, historical responsibility etc.) using an integrated assessment model, GCAM (Global Change Analysis Model). We examine short & long-term distributional impacts on national energy goals (access, affordability, clean energy, efficiency and imports) to identify pathways which offer co-benefits across multiple goals in 32 global regions. Next, we downscale the impacts to the household deciles in India & the US, to scrutinize the residential energy burden change relative to the business-as-usual scenario, while accounting for changes to the average disposable income in each income strata.




**Results.** Our results show significant regressive impacts on access and affordability across mitigation pathways. The effects are higher in India relative to the US. Technology-oriented pathways which increase energy access, without improving affordability for the vulnerable population deciles increase the energy burdens. Global effort sharing could reduce such burdens, but effects remain regressive. Effort sharing based on grandfathering & historical responsibility have contrasting effects in India & US. Pathways which prioritize behaviour change, societal transformations and non-$CO_2$ emission reductions were found to have progressive effects.

**Conclusions.** The findings suggest that different mitigation pathways to similar climate outcomes could have dissimilar effects. We also demonstrate that technology solutions are unable to redress pre-existing inequities and societal change and international effort sharing could suggest progressive options for just transitions. Our work offers policy relevance – showing the importance of underlying systemic changes to achieve social & climate goals, while adding to the evidence supporting trade-offs on energy access for vulnerable populations in mitigation scenarios. The next step in this work is to use a detailed fuel choice model based on MESSAGE-Access to more accurately characterize the household choices by income strata & examine interventions to alleviate these inequities.

# From Waste to Resource? Obstacles and Leverage Points for a more Sustainable and Circular E-waste Management in the EU

Nora Krenmayr, University of Natural Resources and Life Sciences, Austria
*Email: nora.krenmayr@boku.ac.at*
IIASA Mentors: Adriana Gomez Sanabria (ECE) and Pallav Purohit (ECE)

**Introduction.** Waste from electrical and electronic equipment (WEEE or e-waste) is one of the fastest-growing waste streams and contains both toxic chemicals as well as precious metals (gold, silver, iron, aluminium, and copper) and plastics. Therefore, e-waste management and recycling pose a unique conundrum of economic incentives and environmental and health hazards. Europe has a high per capita production of e-waste, but also shows the highest formal collection and recycling rate globally with 42.5%. This can be attributed to EU policies, pursuing a collection rate of 65% and setting targets for reuse and recycling for different categories of WEEE, as part of efforts towards building a circular economy through higher resource efficiency.

**Methodology.** The exploratory study aims to identify obstacles and leverage points for the implementation of these targets and follows a qualitative research design, including a literature review, document analysis and thirteen semi-structured expert interviews. Interviews were conducted with representatives from academia, business interest groups, hardware producers, recycling companies as well as public administration and government. They were transcribed and coded with Atlas.ti with obstacles and leverage points as overarching categories, which were aligned to the stakeholder groups: consumers, hardware producers, recyclers and policy and standardization.

**Results.** A major obstacle for a more circular e-waste management is the lack of collection due to stockpiling at home by consumers, improper disposal in municipal waste, unreported collection and informal recycling. Further obstacles on the part of the producers are 1) lack of product specific information for repair, reuse, and recycling, 2) limited software updates and provision of spare parts, 3) planned obsolescence of products (e.g., embedded batteries), 4) use of wide variety of plastics in products that limit recovery, 5) pressure to keep prices low and make profits, 6) contesting perceptions of what a sustainable product is.
On the part of the recyclers the following obstacles were identified: 1) lack of economic incentives and sorting technology to recycle all materials, 2) high labour costs that drive mechanical dismantling instead of manual dismantling, which produces purer material fractions, 3) high upfront investment and ramp-up periods for recycling facilities, and 4) complicated notification systems for shipment. Generally, there is insufficient cooperation between producers and recyclers and a constant time gap between production and recycling of products leading to recycling technologies lagging and contradictions regarding recycling targets and the changing regulation on hazardous substances. Therefore, interviewees pointed to the importance of a clear alignment between EU and national legislation on products, waste and chemicals.
Further leverage points in policy are: 1) standardization of indicators, measurement methodologies and labelling, 2) a revision of the mass-based quotas for collection, reuse and recycling putting a focus on the recovery of precious and critical raw materials and quality of the recycled material, 3) mandatory standards for companies involved in collection, reuse and recycling, and 4) increased market surveillance.

**Conclusions.** Closing material loops and ensuring high standards of recycling requires changes in production and consumption patterns, stricter regulation and harmonization among EU member states as well as cooperation between all stakeholders along the value chain. The EU is taking important steps into this direction with the proposal of the Sustainable Product Initiative, which promotes durability, repairability and recyclability of products and seeks to enhance resource efficiency in addition to energy efficiency and boost circular business models.

# Methane emissions from global abandoned oil and gas wells

Tianyang Lei, Tsinghua University, China
*Email: leity19@mails.tsinghua.edu.cn*
IIASA Mentor: Lena Höglund-Isaksson (ECE)

**Introduction.** Abandoned oil and gas wells are potential crucial sources of methane emissions, however, with large uncertainty. There are millions of active and abandoned oil and gas wells worldwide which release methane and that will continue to leak also with the shutdown of wells. Methane emissions accounting from abandoned wells worldwide are largely overlooked in emission reports, e.g., the IPCC AR6. The actual numbers, methane flux, and geology-related details of them remain poorly understood. Particularly vital would be to identify the high emitters and to project the potential for continued methane emissions during an energy transition away from fossil fuels in the future. The purpose of this study is to improve the knowledge base on this issue by developing a time-series, resource-type-specific emission inventory for global abandoned oil and gas wells at the well/field/company/country levels. This will allow us to evaluate the methane emissions of targeted contributors and to support the process to reduce methane emissions in view of global climate targets.

**Materials and Method.** We integrated multi-data sources (GlobalData, DEP, Google Map, Energy Monitor), compiled and developed a new time-sequence global abandoned oil and gas wells inventory, encompassing 2,224,547 oil and gas wells in 121 countries. On the basis of a survey of the few measurements that exist of methane emissions from abandoned wells (e.g., Kang et al. 2014, 2016; Williams et al. 2021, Netherlands and UK studies), we estimate the country-level annual methane emissions of the abandoned wells using the following equation:

$E_{c,t} = \sum_{i=1}^{N} EF_{i,j,t}$,
where *c, i, t, j*, represent the country, wells, year, and district (state, city), respectively. *E* represents country-level emissions (t), *N* represents the numbers of abandoned wells in each country (t); $EF$ represents the emission factors (t methane per abandoned wells). The emission factors differ depending on whether wells are plugged or unplugged, oil + gas mix or gas.

**Results.** Due to the lack of specific information on the shutdown date of each abandoned well, we assumed that all abandoned wells drilled prior to 2010 were abandoned before 2010. According to our preliminary estimates, the number of abandoned wells grew from 2.1 million in 2010 to 2.2 million in 2021, with the associated methane emissions increasing from 34 thousand metric tons (kt) to 35 kt in an all-plugged scenario, and from 230 kt to 236 kt in an all-unplugged scenario. From 2010 to 2021, we noticed that more than 90% of global total cumulative methane emissions from abandoned wells come from the US lower 48 states, accounting for 91% in the all-plugged-in scenario, and 95% in the all-unplugged scenario, respectively. This can likely be referred to the large number of wells drilled historically in the US.

**Conclusions.** Abandoned oil and gas wells are potentially a significant source of methane emissions, and that they are timely plugged is critical to reducing leaking methane emissions and meeting global emissions reduction targets. In particular, the US lower 48 states could reduce global emissions from abandoned wells by almost 4 times if all of their abandoned wells were plugged in. Furthermore, we highlight that the spatial concentration of methane emissions from abandoned and active wells is entirely reversed and that developing regions have high methane emissions from active fields but low methane emissions from abandoned fields. Given the increasing number of oil and gas well shutdowns that the future energy transition may trigger, accurate information on the number of oil and gas wells in operation and proposals for drilling and exploration and ways to reduce leakage from abandoned oil and gas wells in both developed and developing regions will be critical to achieving future climate goals.

# Macroeconomic and household impacts of energy transformation pathways for Paris Agreement temperature goals

Osamu Nishiura, Kyoto University, Japan
*Email: nishiura.osamu.56s@st.kyoto-u.ac.jp*
IIASA Mentors: Volker Krey (ECE), Oliver Fricko (ECE), and Bas van Ruijven (ECE)

**Introduction.** Different kinds of IAMs have been developed for specific targets. AIM/Hub model, which is one of the CGE based IAMs, has been applied for social problem caused by emission reduction because this model considers multiple sectors and commodities. On the other hand, it's difficult for this model to simulate large-scale energy system change with long term perspective it has poor representation of energy system and myopic optimization process. In this research, we developed an IAM by combining the MESSAGEix model, a perfect foresight energy system model, with AIM/Hub. This model allows us to estimate emission reduction scenarios considering long-term investment and large-scale change in the energy system and to provide detailed economic implications.

**Methodology.** This research links MESSAGEix and AIM/Hub. Each model solves the emission reduction scenario and baseline scenario for the years 2015 to 2050, and the result from each model provides inputs to the other model. MESSAGEix calculates energy-related information such as the energy mix in each sector. Economic information from AIM/Hub is input into MESSAGEix as changes in energy service demand for each sector. Ideally, this iteration is repeated until reach convergence. In this work, this data exchange is repeated 8 times because AIM/Hub cannot find solution in 9$^{th}$ iteration. In the emission reduction scenario, a common carbon price is introduced to the two models. The carbon price increases at a rate of 5% per year, reaching 94$/Gt-CO2 in 2050.

**Results.** In the emission reduced scenario, reductions begin in 2020 and by 2050 $CO_2$ emission is 46% lower than in the baseline. For final energy consumption, the difference between the two models is reduced by eight exchanges of data. Electricity accounts for a larger share of the final energy consumption in the emission reduction scenario compared to the baseline scenario. Electricity accounts for 44% of final energy consumption. For the household consumption, the loss is larger up to 2030 and the loss is smaller after 2030 comparing to stand alone AIM/Hub output. The population at risk of hunger, calculated from household food consumption and prices, is increased by 16.4% in 2050 due to emission reduction.

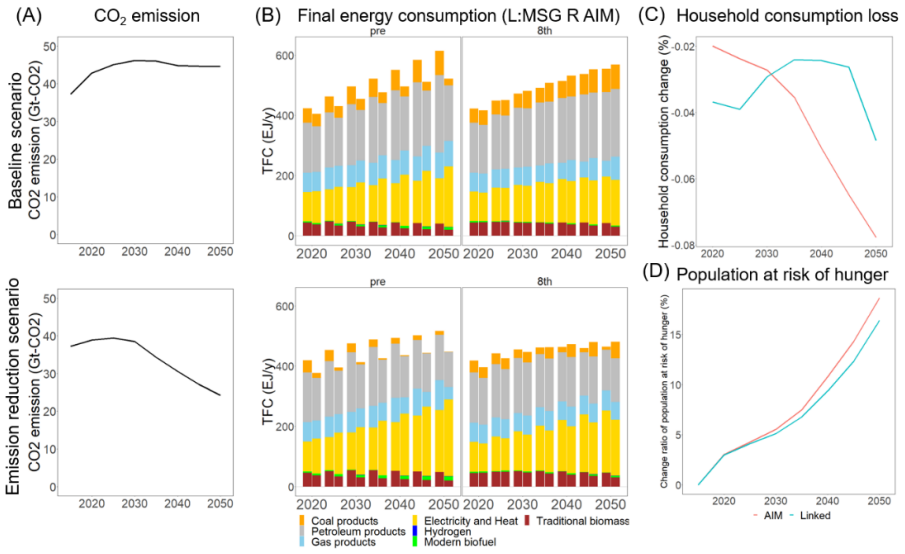



*Figure. Panel(A), (C) and (D) show the result from AIM/Hub after 8 iterations and panel (B) shows the result from both models before (pre) and after 8th iteration.*

**Conclusions.** This research combined the MESSAGEix model and the AIM/Hub model to complement each other's characteristics and applied $CO_2$ emission reduction scenario. This model can provide information such as household consumption and prices of commodities while considering detailed energy system representations. This economic information can be used to calculate information on social issues such as populations at risk of hunger.

# The speciated NMVOC emissions change due to emissions control policy and its impact on air quality

Minwoo Park, Konkuk University, South Korea
*Email: pmw2891@gmail.com*
IIASA Mentors: Younha Kim (ECE) and Zbigniew Klimont (ECE)

**Introduction.** Non-Methane Volatile Organic Compounds (NMVOCs) is one of the important factors that affect climate change and air quality by playing an important role in the formation of $PM_{2.5}$. Since NMVOCs are one of the precursors of Secondary Organic Aerosol (SOA) which make up the majority of $PM_{2.5}$ in atmosphere along with $NO_x$ and $SO_2$, many countries are trying to reduce the $PM_{2.5}$ concentration through emission reduction policies and technologies. Therefore, it's critical for understanding the mechanism of formation of secondary pollution and devising effective control policies and technologies. We developed a policy-technology-based VOC speciation profile that can support air quality modelling to understand future specified VOC emissions and applied it to future emissions pathway to analyse impact to air quality in a Northeast Asia test case. In addition, the speciated future VOC emission will be used in the air quality model to forecast and evaluate emissions under the reduction policy scenarios in East Asia.

**Methodology.** In this study, we analysed the impact of the change in VOC emissions and the air quality. For this work, 1) VOC speciated profile DB was established, especially considering control technology-specific information. 2) the future emission scenario up to 2050 was created using the GAINS model, and 3) the effectiveness of the speciated emission change was evaluated by replacing VOC speciation profile and CTM (Chemical Transport Model) was used for a better understanding of chemical composition and the comprehensive evaluation of the effectiveness of VOC reduction.

**Results.** The solvent use sector is the dominant emitting sector which accounts for the largest share in Korea (54%), China (36%) and Japan (57%), and followed by the industry and transportation sectors. Figure 1 shows the change in the composition of VOC emissions according to the policy in the paints sector. Replacing solvent-based with water-based paint reduces total VOC emissions as well as the aromatic chemical species which is known as the high potential. It leads to a significant decrease in the emission of SOA.

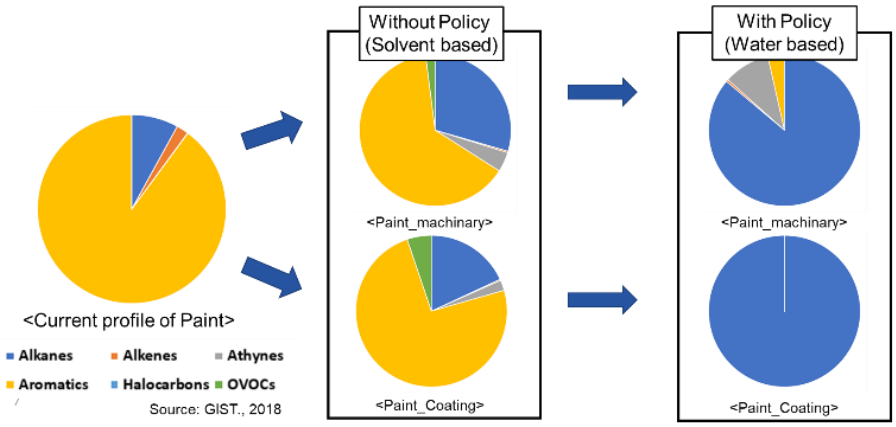



*Figure 9. VOC speciation profile by without policy and with policy*

**Conclusion.** In this study, VOC speciation profiles were improved and specified to technology. This sector-specific chemical information contributed to changes in PM2.5 concentration up to 20%. Based on these results, we can expect effective emission reduction scenarios by major emission sectors for each country can be established through the evaluation of the effectiveness of this study's policies and technologies.

## References

GIST, K_ACheMs 3rd year final report, 2020
Conceicao A. R. da, Pimenta E. A. R., Fujisawa R. S., and Nohara E. L., (2012). Comparative Study of the Quantity of Volatile Organic Compounds in Water-Based Paint and Solvent-Based Applied Polyurethane. Macromol. Symp. 316: 108-111.

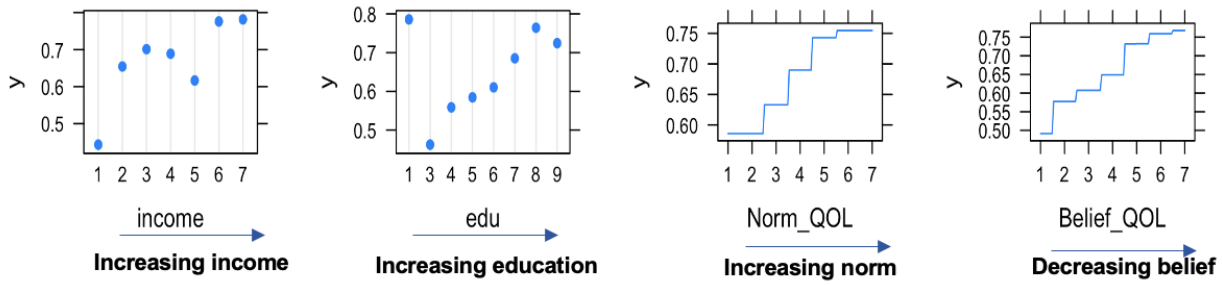
# Understanding the relationship between norms, beliefs and appliance ownership in urban India and the U.S.

Pooja Ramamurthi, Princeton University, USA
*Email: pvr@princeton.edu*
IIASA Mentors: Shonali Pachauri (ECE) and Narasimha Rao (ECE)

**Introduction**. Although literature has highlighted the importance of lifestyle change on carbon emissions, most energy demand models tend to consider individuals as rational, driven solely by monetary concerns such as income and price of technology. Lifestyle factors, which are influenced by psychological, sociological and cultural determinants do impact intentions and goals around energy use behaviour. Empirical work that has examined non-monetary factors tends to focus on industrialised countries alone, and the intent and motivation to take-up sustainable lifestyles in emerging countries is currently understudied. Our work studies electrical appliance ownership trends across India and the U.S. and then determines which norms and beliefs are associated with individuals who own 'aspirational' appliances in the two countries.

**Methodology.** In our study, we use two unique datasets of urban individuals in the U.S. and India which contain psychological variables and appliance usage data. Using an appliance ladder and descriptive statistics, we identified appliances which are considered aspirational appliances in each country. Based on secondary literature, we chose four norms and beliefs that we hypothesised would be associated with the ownership of these aspirational goods. These non-monetary variables were associated with appliance usage for 'quality of life', 'economic worth', 'social status' and 'environmental' motivations. Using logit analysis and machine learning techniques of gradient boosted machines and decision trees, we determined which socio-demographic and psychological variables were most associated with the aspirational goods and vice-versa in each country.

**Results.** Air conditioners (AC) and dishwashers (DW) were identified as aspirational appliances in India and the U.S.,




respectively. Along with certain socio-demographic variables, in India, beliefs, and norms that an aspirational appliance is essential for good quality of life was most significantly correlated with AC ownership. In the U.S. DW ownership was associated with beliefs around quality of life and economic value of the appliance. In both countries social norms and personal beliefs acted in same way. Individuals who strongly believed in the value of the appliance were less likely to own the appliance. However, if individuals perceived that everyone valued the appliance, they were more likely to own the appliance (shown in Figure). This could indicate that individuals who own the appliance get habituated or take the appliance for granted thereby placing lower value on the appliance than those who don't own them.

**Conclusions:** Our findings show that socio-demographic and economic factors are not sufficient to understand appliance ownership trends. Psychological factors such as beliefs and norms are also relevant and need to be included in models to improve behavioural realism. Further, the types of norms and beliefs as well as the strength of their association with appliance ownership is context- specific and varies across countries.

# Triangulation of stock-flow indicators of material cycles from MESSAGEIX and industrial ecology

Jan Streeck, University of Natural Resources and Life Sciences, Vienna, Austria
*Email: jan.streeck@boku.ac.at*
IIASA Mentors: Volker Krey (ECE) and Gamze Ünlü (ECE)

**Introduction.** Material production is responsible for ~1/4$^{th}$ of global GHG emissions, making material cycle modelling important for decarbonization research in Integrated Assessment Models (IAMs).[1] To adequately assess prospective scenarios of decarbonizing material cycles, it is key to quantify current cycles, as these influence future dynamics. However, accurate and comprehensive quantification of material cycles is challenging, which merits the validation of indicators across methods.[2,3] This work compared the ongoing quantification of major material cycles in the IAM MESSAGE*ix* with independent estimates from Industrial Ecology studies.

**Methodology.** We compared ~2015 material stocks and flows for the USA and Canada from MESSAGE*ix* to six other studies. Studies represent three different methodologies of Material Flow Analysis, i.e. stock-driven remote sensing based,[4] stock-driven statistics based,[5–8] and inflow-driven economy-wide models,[9] the latter of which was advanced in this work. Sectoral focus was on power, residential and non-residential buildings but data for motor vehicles, roads and other sectors were collected for future comparison. We explained emerging differences by examining underlying data, for example activity (e.g., m² floor area) and material intensity (kg/m² floor area).

**Results.** For overlapping system definitions, total material stocks varied by a factor of up to three among studies, stocks by material by up to > 10 over the three sectors power, residential and non-residential buildings. For stock-driven studies, the varying stock levels could be explained by largely differing activity levels (e.g. statistics U.S. gross floor area, GFA, 2015: 22 billion m²; remote-sensing USA GFA 2021, estimated 45-51 billion m²) and/or material intensities (up to factor > 20 differences). Additionally, we found that power grids were not considered in MESSAGE*ix* but for aluminum, copper and steel made up 39-98% of power sector material stocks; and for bricks, the reported cumulative apparent consumption from 1870-2017[9] was < 60% of a bottom-up material stock estimate.[4]

**Conclusions.** The large differences of material stock estimates call for improved data and data reconciliation of activity levels, material production, end-use shipments, material intensity, as well as for cross-method analysis. Data differences might result from using activity data assembled for purposes other than material cycle modelling,[10] few available case studies on building material intensities, and non-market material extraction which does not find its way into statistics (e.g. for bricks). For momentary modelling of climate change mitigation through material efficiency, our results stress the need to explicitly address uncertainty, for example through sensitivity analysis.

## References.

1.Hertwich EG. Increased carbon footprint of materials production driven by rise in investments. Nat. Geosci. 2021; 44: 1888.
2.Tanikawa H, et al. A framework of indicators for associating material stocks and flows to service… J. Clean. Prod. 2021; 285: 125450.
3.Chen W-Q. Dynamic Product-Level Analysis of In-Use Aluminum Stocks in the United States. J Ind Ecol 2017; 22: 1425–1435.
4.Frantz D, et al. High-resolution material stock maps for the USA. In preparation.
5.Berrill P and Hertwich EG. Material flows and GHG emissions from housing stock evolution…. Buildings and Cities 2021; 2: 599–617.
6.Pauliuk S, et al. Global scenarios of resource and emission savings from material efficiency in… Nat Commun 2021; 12: 5097.
7.Deetman S, et al. Projected material requirements for the global electricity infrastructure… Resour Conserv Recycl 2021; 164: 105200.
8.Kalt G, et al. Material stocks in global electricity infrastructures... Resour Conserv Recycl 2021; 173: 105723.
9.Streeck J, et al. The role of socio-economic material stocks for natural resource use in the United States... J Ind Ecol 2021; 140: 1880.
10.Arehart JH, et al. A New Estimate of Building Floor Space in North America. Environ Sci Technol2021; 55: 5161–5170.

# Future scenario of residential hourly cooling energy demand in the United States

Gesangyangji, University of Wisconsin-Madison, US
*Email: gesangyangji@wisc.edu*
IIASA Mentors: Alessio Mastrucci (ECE) and Edward Byers (ECE)

**Introduction.** To support adaptive planning measures and inform demand-side energy conservation, it is important to understand future changes in cooling energy demand and their variations on different time scales. In particular, reliable projections on changes in temperatures and cooling demand throughout the day are key to manage intra-day variations in buildings energy demand, integrate high penetration of renewable energy, balance peak load, and assess overexposure on hot summer days. This study quantifies the changes in hourly cooling energy demand in the U.S. residential sector under different climate futures.

**Methodology.** Future temperatures on an hourly scale were produced from projected daily maximum and minimum temperatures and historical hourly fractions, and were used to calculate intra-day variation in cooling demand due to temperature rise, refer to as cooling degree hour (CDH). By using the building stock energy demand model MESSAGEix-Buildings, we also account for socio-economic changes including population, building characteristics, and behaviors-related parameters. Temperature profiles, CDH and cooling energy demand are calculated on a monthly basis using representative daily profiles for different temperature conditions and future scenarios.

**Preliminary results.** We show here illustrative results for CDH in the case of extreme hot days in the ssp585 scenario. We found increases in daily cumulative CDH (Fig.1, A) over the most part of the US, except in the west costal area, and the most increases are seen in the Mid-Atlantic area. Fig 2, B shows hourly CDH profiles in extreme days for selected locations in different climate zones. The magnitude of changes between historical and future CDH varies between cities and throughout the day. In Orlando and Atlanta, larger increases in CDH will occur in the afternoon, while in Baltimore in the evening and night-time. The least increases are in Minneapolis with little intra-day variations. As a result, Orlando and Atlanta would expect larger diurnal variations in the cooling demand, while Baltimore and Minneapolis would have less intra-day variation.

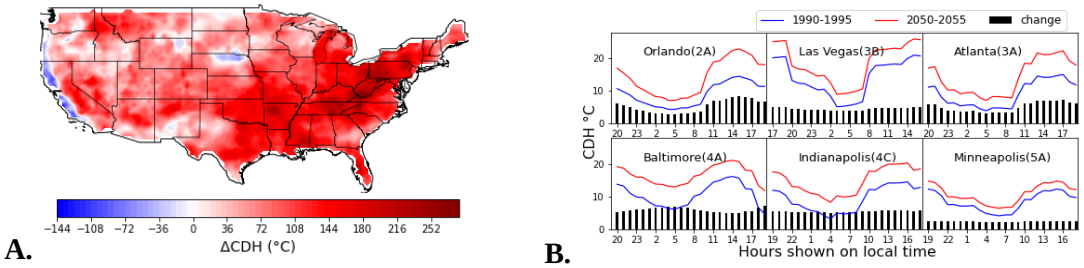



*Fig. 1, Cooling Degree Hours (CDH) in 2050 in the ssp 585 scenario in the U.S.: A. changes in cumulative CDH in extreme hot days. B. CDH profiles for extreme days at selected locations.*

**Conclusions.** Our results indicate that the magnitude of changes in future cooling demand (CDH) will vary across the US and throughout the day, which will change the daily pattern of cooling energy demand differently in individual cities. These results highlight the importance of evaluating the intra-day energy demand and will inform local adaptive planning measures and energy conservation strategies. Next, we will continue analyzing representative daily profiles for different months, and calculate the cooling energy demand at hourly resolution.

# *Economic Frontiers*
# *(EF)*

# Analyzing the income distributional effects of carbon taxation with revenue recycling – case of British Columbia

Andreas Lichtenberger, The New School for Social Research, United States
*Email: andreas.lichtenberger@newschool.edu*
IIASA Mentors: Michael Kuhn (EF), Fabian Wagner (ECE) and Miguel Sanchez Romero (EF)

**Introduction.** A big issue around carbon taxation is its political feasibility. However, carbon tax revenues can be recycled in various ways and research showed the positive social and environmental aspects of a carbon tax with recycled revenues. So far, no study has analyzed the redistributive character of revenue recycling carbon tax implementations for observed consumer expenditure data. I intend to close this gap and help policymakers with regards to a carbon tax implementation with a climate rebate program by researching the case of British Columbia (BC) in Canada which was the only territory in Canada to introduce a carbon tax with revenue recycling back in 2008.

**Methodology.** The study is based on Canadian Survey of Household (SHS) expenditure data with annual observations between 2002 and 2019 for all territories and five income groups (quintiles). I use the scenario of BC introducing a carbon taxation scheme in 2008 as a quasi-experimental setup that I investigate with a Difference-in-Difference approach for the different income groups. I compare the tax burdens with the recycled carbon tax revenues to low-income households to estimate the re-distributional effect of the policy across the different income groups.

**Results.** The carbon tax in BC was introduced at a low level of \$CAD 10/t$CO_2$, increasing to \$CAD 30/t$CO_2$ until 2012. Given the respective tax on car fuels the accompanying revenue recycling program was high enough to offset burdening effects for low-income households (see Figure 1). However, the scales also reveal very low effects in total for higher income groups on an absolute and relative scale (below 0.2% of post-tax income). Compared to other households I find that the highest income group shows a consumption decrease of car fuels which might also indicate a substitution of fossil fuel driven individual transportation forms. However, consumption share developments based on disposable income do not show a relaxation of lower income household budgets (see Figure 2). Due to the small price effects a difference-in-difference estimation does not find a strong impact of taxation and rebatement on consumption shares relative to disposable income.

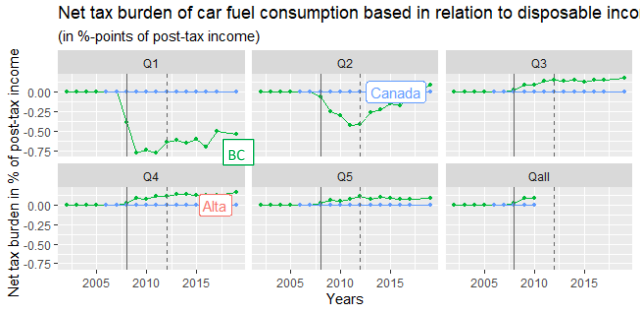



*Figure 1: Net tax burden effect of the BC carbon tax revenue recycling scheme*

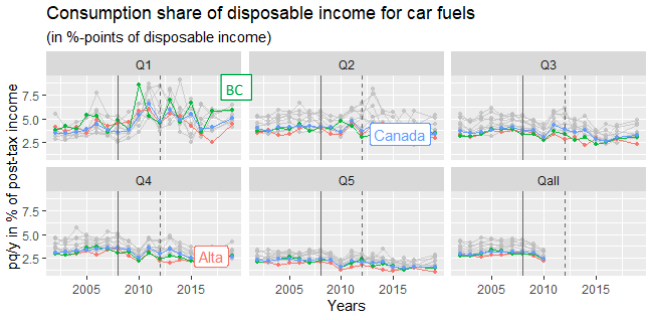



*Figure 2: Expenditure share of car fuels based on disposable income*

**Conclusions.** The carbon tax dividends in BC lower the net tax burden for lower income households in relation to car fuel consumption. However, based on the low tax rate I do not detect significant effects of the tax policy with regards to consumption changes. Hence, for a more relevant effect policymakers need to (a) think about higher carbon tax rates, and (b) introduce a carbon dividend scheme that is also able to mitigate external price fluctuations.

# How to prepare and adapt to a climate tipping point

Maddalena Muttoni, University of Padova, Italy
*Email: mmuttoni@math.unipd.it*
IIASA Mentor: Stefan Wrzaczek (EF)

**Introduction.** The well-known DICE model, developed by William Nordhaus, is a dynamic model that investigates the interactions between industrial production and global warming, providing tools to plan an efficient emission abatement policy. Among its limitations, there is the lack of uncertainty regarding the possibility of a sudden climate event that may change abruptly and permanently the nature of the system, defined as a *tipping point* (e.g., complete Arctic ice melt, standstill of the Gulf Stream). We integrate the threat of a tipping point in the DICE model and analyze its dual effect: the behavioral change in *anticipation* of the event, and that in *adaptation* to the new regime.

**Methodology.** We formulate the problem as a finite-time, two-stage optimal control problem, featuring a random switching time to represent the instantaneous occurrence of a tipping point; we refer to Stage 1 and 2 as the time interval before and after the switch, respectively. The policymaker's utility and the Stage 1 dynamics are a continuous-time adaptation of the DICE model implemented in GAMS. Depending on the specific scenario, we may model the effect of the tipping point as a change in the dynamics' parameters, or as a discontinuity in the state trajectory at the switching time. Applying the Maximum Principle for heterogeneous systems, we obtain and analyze the necessary conditions for the optimal strategies.

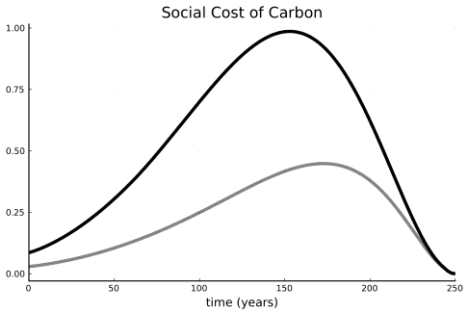
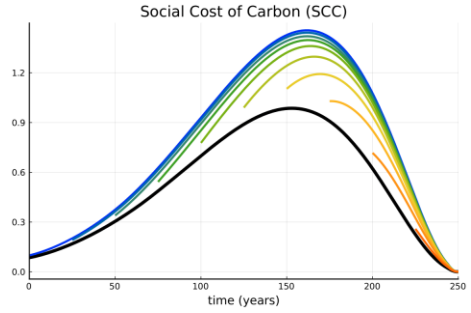



*Fig.1: Anticipating (black) vs non-anticipating (gray)*

*Fig.2: Stage 1 (black) vs Stage 2 (color)*




**Results.** We formulate a hazard rate that grows linearly with temperature and consider four scenarios with different tipping points: A) the complete Arctic sea-ice loss, B) destruction of capital entailed by an environmental catastrophe, C) an increase in the impact of temperature on production, and D) the transformation of a carbon sink to a carbon source. The *anticipating* effect is evident when comparing the optimal management in Stage 1 with that in the absence of a tipping point (fig.1); the *adapting* effect is observed when comparing the optimal behavior in Stage 1 with that in Stage 2, for different realizations of the switching time (fig.2): in this type of graph, the variable's evolution is represented by the black line up until the switching time $\tau$, afterwards it is represented by the colored line that starts from $\tau$. Both figures correspond to scenario A: with our approach, we are able to compute the Social Cost of Carbon (SCC) and to decompose its value into different factors' contributions (not in the figures).

**Conclusions.** In all four scenarios, *anticipation* of the tipping point results in higher emission abatement and SCC. The goal is to keep temperatures low in order to reduce the hazard of a tipping point. Savings are significantly different from the non-anticipating case only in scenario B, where they are lowered to keep capital small, in the aim of limiting the damage. *Adaptation* to the tipping point (i.e., the change in behavior from Stage 1 to Stage 2) depends on the scenario: the savings rate varies significantly only in scenario B, where no permanent change affects the system and capital is rebuilt by increasing savings and lowering abatement and SCC; in all other scenarios, abatement can become higher or slightly lower depending on how effective it is at keeping carbon levels low and on how convenient it is to keep temperatures low.

# *Population and Just Societies (POPJUS)*

# Risk justice: boosting risk management contribution to sustainable development

Mathilde de Goër de Herve, Karlstad University, Sweden
*Email: mathilde.degoerdeherve@kau.se*
IIASA Mentors: Thomas Schinko (POPJUS) and John Handmer (POPJUS)

**Introduction.** The literature suggests that consideration of justice in risk management is crucial for promoting its contribution to sustainable development. The novel framework presented here and named *risk justice* supports the operationalization of a fair management of possible negative events. As sustainable development covers various facets, risk justice also needs to consider several overlapping dimensions: social, ecological, spatial, and temporal.

**Methodology.** The present research work includes two methods. First, theory building is used to create the conceptual risk justice framework, by crafting an ensemble of logically connected ideas. This conceptual work groups envisioning and explicating tasks, since it characterizes different aspects of justice and shows their relevance together as a whole. It is based on existing scientific literature topped by ideas provided by informal discussions with recognized scientists in the field. Second, the analytical potential of the framework is illustrated with a document analysis application. International disaster risk management guidelines have been selected and their content analysed under the risk justice lens: the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) and the European Flood Directive (EFD).

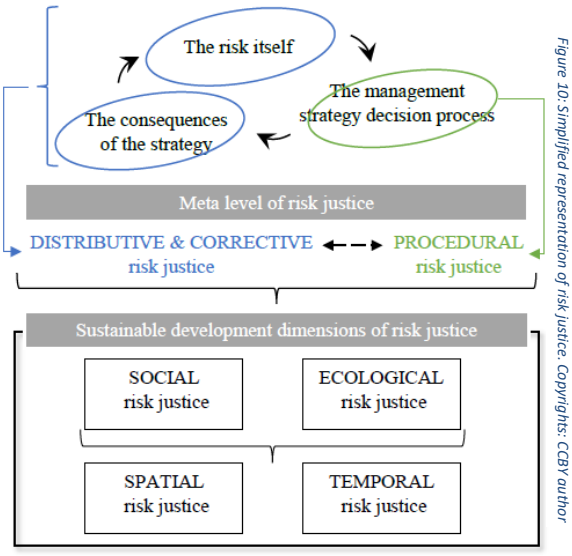



*Figure 10: Simplified representation of risk justice. Copyrights: CCBY author*

**Results.** Risk justice gathers distributive, corrective, and procedural justice that are relevant in the risk management processes (Figure 1). The novelty of the framework is to consider all of them under four perspectives relevant for sustainable development: social and ecological issues within various spatio-temporal dimensions. Therefore, risk justice insists on the contribution of risk management to sustainable development through the integration of fairness considerations for humans, non-humans, here and there, yesterday, today, and tomorrow. The SFDRR clearly states that disaster risk management is contributing to sustainable development, yet, when analysed under the risk justice lens, it reveals unbalanced considerations for the different dimensions. Procedural justice is in focus with the participation of all stakeholders in the decision-making process, including younger ones, but with no clear mention of representatives for non-human interests. The emphasis on international cooperation touches upon distributive and to some extend corrective justice because of climate change. In term of distributive justice, social and temporal aspects are also included, notably with the priority given to preventive actions. The EFD focuses on spatial issues within river basins and between the Member States, and ecological issues are addressed through the coordination with the Water Framework Directive. Social and temporal issues are less emphasised.

**Conclusions.** Neglecting justice considerations in risk management might limit its capacity to foster the different dimensions of sustainable development. Trade-offs are necessary and probably inevitable, yet, international guidelines for risk management would encourage a broader system-thinking by addressing explicitly all aspects of risk justice. The framework is used here as a backward-looking tool to analyse the emphasis on some fairness aspects rather than others in official documents. In addition, risk justice could also be applied as a forward-looking analytical tool, in order to facilitate transparent choices with clarified fairness positions within risk management.

# Bilateral international migration measurement and forecast: an agent-based model

Xinyi Kou, University of Manchester, UK
*Email: Xinyi.kou@postgrad.manchester.ac.uk*
IIASA Mentors: Guillaume Marois (POPJUS) and Dilek Yildiz (POPJUS)

**Introduction.** Because of the low fertility and mortality in Europe, international migration is becoming an increasingly important factor in shaping population structures. As the most challenging demographic component, international migration studies suffer from the forecasting uncertainties. The uncertainties are categorized into two groups, i.e., epistemic uncertainty and aleatory uncertainty (Bijak and Czaika 2020). The epistemic uncertainty is rooted in the difference on defining a migrant, and stems from the imperfect measurement of migration and data deficiency, while the aleatory uncertainty is the inherent uncertainty due to the probabilistic variability or other types of randomness, stems from the individual migration decisions in migration studies. This research aims to address the migration uncertainties by explaining the underlying mechanisms of migration behaviour, and forecast the bilateral international migration flows to 2030 between Poland, Germany, and United Kingdom.

**Methodology.** The agent-based model (ABM) is a computational model to understand the behaviour of a complex system. It simulates the action and interactions between autonomous agents through the individual decision-making rules. In this research, the decision rules of migration behavior are governed by the theory of planned behavior (TPB) (Ajzen 1985). This psychological theory maintains that a particular behavior action is explained by the individual's behavioral intentions, which consists of three core components, 1) attitude towards migration, considered as the reasons of migration behaviour; 2) subjective norm for migration, which measures the social pressure of their peers; 3) perceived behavioural control over migration, which captures the ability of a person to make an actual migration action. The model inputs are obtained from the OECD dataset. All the annually data are transformed into monthly data by simply dividing 12. The model parameters are random selected from the uniform distribution for the theoretical model simulation. Parameters are calibrated later to improve the model accuracy.

**Results.** The theoretical ABM simulation with random inputs and parameters shows that the model has the ability to produce not only the bilateral migration flows, but also the number of migrants and other disaggregate migration data. By incorporating the real dataset, the ABM sample 1000 persons for each country, and run the simulation monthly from 2002 to 2030. The results show a relatively flat migration pattern over period 2002-2030, with highest migration flows corridor between Germany and UK, and lowest migration flows corridor between Poland and Germany. We observe that the migration flows change dramatically when varying the model parameters. Therefore, the results are still uncertain if the model parameters are not well addressed.

**Conclusions.** The ABM model explains the migration decision-making process of an individual through the TPB, the model shows its advantage on incorporating both macro-, meso- and micro-level variables simultaneously. Our analysis reveals that the model is quite sensitive to the model parameters. This finding suggests that a further step on sensitivity analysis and parameter calibration can be done to improve the model accuracy. A more efficiency sensitivity analysis method for this agent-based model has to be considered.

## References

Bijak, J., & Czaika, M. (2020). Assessing uncertain migration futures: A typology of the unknown. *Changes*, *1*(5).
Ajzen, I. (1985). From intentions to actions: A theory of planned behavior. In J. Kuhl & J. Beckmann (Eds.), *Action control. From cognition to behavior* (pp. 11–39). Springer.

# Land use change and vector-borne disease as an ecological determinant of health: A scoping review

Thomas G. Leffler, MPH, Center for Sustainability and the Global Environment, University of Wisconsin-Madison, USA
*Email: tleffler@wisc.edu*
IIASA Mentor: Roman Hoffmann (POPJUS)

**Introduction.** The relationship between land use change and human development is a complex association rooted in factors relating to ecology and the biome, geology, and human activity such as agriculture and livelihood provisioning. It is additionally subject to global anthropogenic forces such as rising temperatures due to global warming. An emerging and understudied aspect of anthropogenic land use change relates to infectious disease risk - both of novel, emerging pathogens, such as COVID-19 and Langya virus, and of established, endemic diseases such as malaria and dengue. As land use changes alter habitats, the ecology of disease vectors may also change in response. These dynamics are understudied and present an emerging challenge to securing global health amid increasing human development and expansion into previously wild areas. This scoping review investigates the dynamics of vector borne disease in response to land use change throughout the tropics, specifically in the Amazon region, sub-Saharan Africa, and Oceania in order to identify commonalities, trends, and emerging themes underpinning infectious disease risk. Auxiliary objectives include analyzing novel pathogen risk from similar pathways.

**Methodology.** Literature searches were performed from PubMed and Google Scholar using the search terms “land use change and infectious disease”, “land use change and vector borne disease”, “land use change and zoonotic disease”, “anthropogenic land use change and disease risk”, and additional articles from bibliographic references to compile 37 studies. These studies were analyzed to summarize findings and identify common themes, broadly based on the following categories: a) direct/mechanistic evidence of land use change on vector borne disease risk; b) evidence of increased novel pathogen risk; c) differences between specific vector borne disease risks, and across specific regions; d) related livelihood and socio-economic factors in disease risk; and e) policy implications and solutions for affected communities.

**Results.** Commonalities and results from the literature showed varied strengths of association between land use change and disease risk, as well as examples in which there was no significant relationship. These drivers can be categorized as: a) alterations to forest habitat and subsequent vector ecology and disease ecology; b) localized hydrological cycle changes associated with human agricultural altering vector prevalence and density; c) decreases in overall biodiversity altering host feeding diversity and subsequent increased risk of pathogen density in remaining, less diverse wildlife populations; d) proximity to livestock and increased livestock density providing vector feeding opportunities in proximity to human habitats.

**Conclusion.** Significant associations between land use change and vector borne disease risk exist, exacerbated by various factors of human action and alteration of local environments, particularly forest clearance for agriculture and livestock production. Solutions to addressing increased disease risk should be comprehensive in addressing the root causes of these ecological changes, while providing public health services and sufficient medical care and access for affected communities.

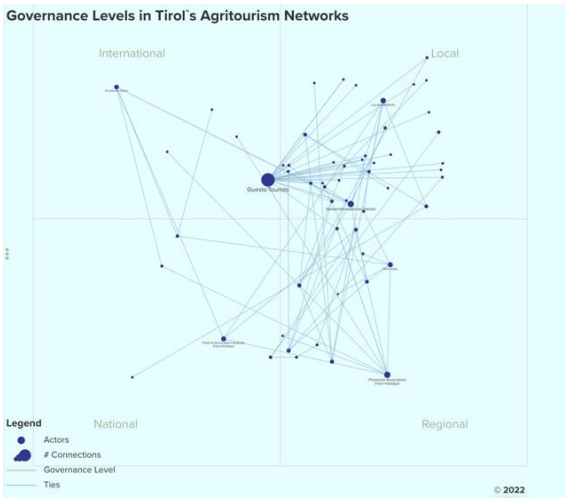
# Integrating stakeholder analysis into qualitative system mapping: An actor-oriented analysis of agritourism networks in Tyrol, Austria

Leonard Kwhang-Gil Lemke, University of Vienna, Austria
Email: *leonard.lemke@univie.ac.at*
IIASA Mentor: Susanne Hanger-Kopp (POPJUS)

**Introduction.** Geography has made great contributions to the history of mapping and modelling of global environmental change, but alongside spatial analysis and big data driven research in the discipline, a qualitative-quantitative divide has emerged. Although qualitative research is increasingly recognized and formalized elsewhere, in Geography, despite its value for making sense of human dimensions of systems, it was frequently denounced as a soft science under scrutiny for lacking scientific rigor. Methods were criticized for being difficult to reproduce and not transparent enough, which called for more transparent and rigorous research processes. This research thus explores new avenues for rigorous qualitative systems mapping (QSM) as a means to capture social network structures.

**Methodology.** The research begins with a review of the stakeholder mapping- and social network- analysis literature and provides insights into state-of-the-art QSM. Then, building on the methodological synergies, these methods are integrated and proposed as qualitative system-based stakeholder mapping. This is further supported by an exploratory case study in the context of agritourism networks in Tyrol, Austria. A total of 28 academic sources were selected and coded on the qualitative data analysis tool MAXQDA in order to obtain a list of actors, natural assets, descriptions and connections. This data was then categorized, imported and visualized using the digital system mapping tool KUMU.IO.

**Results.** QSM is still at an infancy state and most research is based on causal loop diagrams where actors and interactions are often not explicit. A social network perspective adds such human dimension, and whilst akin to system thinking in QSM, only differs with respect to the level of aggregation and the nature of the nodes and connections. The exploratory mapping of stakeholders, natural assets and connections in agritourism provided first analytical insights into Tirol's regional specificities. The Figure illustrates, how the network spans across administrative levels and different sectors, whilst also displaying heterogeneous linkages including funding streams, policy mandates and information flows amongst others. The applied actor-oriented lens of QSM further demonstrates the interaction between humans and natural assets that enables a holistic systems perspective, which challenges researchers to carefully reflect on the types of nodes selected and on what terms they are being connected and visualized.




**Conclusions**. Integrating stakeholder into QSM has promising entry points to harmonize social and ecological systems research in human geography. The literature review and case study emphasize the value of QSM as a means to capture social networks as parts of regional ecosystems. The methodological value emerged particularly for scoping- and base-line studies and thus proposes QSM as an intermediate step to grasp local context. Although these maps only depict an abstraction from reality and do not strive for completeness, the diversity of actors and interactions identified open analytical doorways for further rigorous qualitative enquiry into regional complexity.

# Measuring global social vulnerability to natural hazards at the sub-national level

Xueting Li, Asian Demographic Research Institute, Shanghai University, China
*Email: lixt021@gmail.com, ali0991@shu.edu.cn*
IIASA Mentors: Raya Muttarak (POP) and Roman Hoffmann (POPJUS)

**Introduction.** Identifying and addressing social vulnerability is an integral element of disaster risk reduction efforts. A range of quantitative approaches have been proposed to measure vulnerability in different contexts, guiding the scale of research and the selection of indicators. Validating the approach of social vulnerability measurement with the actual impacts of natural hazards is necessary for comprehensively understanding the interplay between hazard, exposure and vulnerability. Here, highly localized studies face difficulties in capturing the common characteristics of societies and comparable factors shaping social vulnerability at a larger scale, challenging comparisons at the global level. This study will investigate global social vulnerability to natural hazards using sub-national data for a large number of countries.

**Methodology.** Referring to the research frameworks of previous literature, several demographic and socio-economic data at sub-national level were collected from Global Data Lab. Considering the data availability, after removing highly correlated variables by multi-collinearity test, there were 7 indicators employed to construct the social vulnerability index (SVI). Firstly, Principle Component Analysis was adopted to construct the SVI using equal weights. Then, by incorporating the effect of demographic and socio-economic context on actual impacts of natural hazards, weights derived from multiple linear regression models were adopted to develop a second set of the SVI. The actual impacts and geolocations of natural hazards data were obtained from EM-DAT and Geocoded disaster dataset. Exploratory spatial data analysis was applied to investigate the spatial pattern of the two different sets of global SVI at sub-national level.

**Results.** Indicators were taken their average value by 5 years' interval since 2000. In total, there were 8813 observations during the period, including 1070 sub-national regions. Using R software, PCA identified 3 principle components at each period, indicating regional characteristics of socio-economic development, household size and population structure, explained about 80% of the total variance. Model results show that the effect of average educated years, proportion of female population over 50 years old, proportion of urban population, average household size on natural hazards fatality is significant, when controlling for total affected population. For total financial damage, the effect of children dependency ratio, international wealth index, also average educated years, proportion of urban population, average household size is significant.

**Conclusion.** Both principle component analysis and modelling approaches were adopted to investigate the demographic and socio-economic context at sub-national level and its interconnection with natural hazards impacts under climate change. This is important for assessing the common characteristics of regional social vulnerability and comparing at larger scale. Further investigation in identifying population subgroups and hotspots incorporating more data is required.

# The causal effect of schooling on overweight/obesity in low- and middle-income settings

Lilipramawanty K. Liwin, School of Demography, the Australian National University, Australia
*Email: lili.liwin@anu.edu.au*
IIASA Mentors: Daniela Weber (POPJUS) and Sonja Spitzer (POPJUS)

**Introduction.** In high-income countries, the average educational attainment is strongly associated with the long-term decline in morbidity and mortality of a population, including overweight/obesity. For low-income countries, however, the effect of education on overweight/obesity may depend on the stage in the nutritional transition (Baker et al., 2017). The effect may be positive at the beginning of the transition, and negative thereafter. While there is some evidence on the education-obesity relationship in poorer countries, these studies rarely establish a causal relationship between educational attainment and overweight/obesity. Hence, this study aims to investigate the causal effect of schooling on being overweight/obese in Indonesia, a low-income country that has experienced growing in obesity.

**Methodology.** This project estimates the effect of years of schooling on being overweight/obese using high-quality individual-level data from the Indonesia Family Life Survey, which provides detailed information on education histories and health status (RAND, 1993). We start by estimating simple probit models. To account for potential endogeneity, we then use exposure to a substantial primary school construction program (SD INPRES) as an instrument for years of schooling (Duflo, 2001). For this, the individual-level data is linked to district-level data, capturing the intensity of the program across regions from 1973-1978. All models control for individual characteristics and region of birth.

**Results.** Preliminary findings based on the simple probit model show a significant positive association between years of schooling and the likelihood of an individual being overweight/obese. In particular, an additional year of schooling increases the probability of individuals being overweight/obese by 0.02, ceteris paribus. We then employ two-stage least squares regression analyses for binary outcomes to elicit the causal effect of education on health. The preliminary results of the first stage suggest that exposure to the education program is a strong instrument, as indicated by an F-statistic of 153.71. Similar to the simple probit model, we find a positive effect of years of schooling on the probability of being overweight/obese in the second stage. This effect is, however, only significant a 10-percent level.

**Conclusions.** Our preliminary results indicate a positive causal effect of schooling on the probability of being overweight/obese. However, there might be some heterogeneity in our findings for different subpopulations. As a next step, we will thus conduct further heterogeneity and robustness analyses. Moreover, this study will be extended to additional health outcomes, in particular diabetes, which is highly associated with overweight or obesity status.

## References

Baker, D. P., Smith, W. C., Muñoz, I. G., Jeon, H., Fu, T., Leon, J., Salinas, D., & Horvatek, R. (2017). The Population Education Transition Curve: Education Gradients Across Population Exposure to New Health Risks. *Demography*, *54*(5), 1873-1895. https://doi.org/10.1007/s13524-017-0608-9

Duflo, E. (2001). Schooling and Labor Market Consequences of School Construction in Indonesia: Evidence from an Unusual Policy Experiment. *The American economic review*, *91*(4), 795-813. https://doi.org/10.1257/aer.91.4.795

RAND. (1993). *Indonesia Family Life Survey*. https://www.rand.org/well-being/social-and-behavioral-policy/data/FLS/IFLS.html

# Cohort fertility differentials from rural/urban migration in Brazil

Camila Ferreira Soares, University of Campinas, Brazil
*Email: ferreirasoares01@gmail.com*
IIASA Mentor: Michaela Potančoková (POPJUS)

**Introduction.** The transformation of a rural into an urban population, in a short period, as in Brazil, may have impacted fertility rates. As in Lech (2019), the aim is to identify if there is an association between migration and fertility and, if so, how much was the effect of migration on fertility. Has internal migration between rural and urban regions slowed down Brazil's fertility decline? We chose to analyse two Brazilian areas that are very different, both in terms of urbanization and fertility, the Northeast (NE) and the Southeast (SE). The choice of time was designed to analyse the first stages of the fertility transition, which resembles the intense period of internal migration in the country.

**Methodology.** We analyse changes in completed cohort fertility of women born between 1921-1945 with respect to their urban/rural residence and migration status using IPUMs microdata from Brazilian censuses from 1970 and 1980. The information on the household situation and the situation of the previous residence enabled us to construct different groups of migrants and non-migrants: rural to urban, rural non-migrants, urban to rural, urban non-migrants, rural total, and urban total. Because we are interested in the impact of migration on childrearing, we only consider those moves those women made end before achieving the age of 40. For cohorts younger than 40 at the census, we estimated competed fertility using Brass and Juarez (1984). Next, we used decomposition of the change in fertility rate to estimate the contribution of migration to fertility change. The decomposition identifies the migratory composition effect (E) and the migration-specific fertility by parity (F).

**Results.** We find that fertility declined among non-migrants and migrants in both regions (Fig1). The fertility decline was faster in the more urbanized Southeast region, where the fertility differentials between the groups narrowed but remained much more pronounced compared to the less urbanized NE. In the NE, fertility decline accelerated only from the 1936-1940 cohort, and urban and rural fertility seemed to decline at about the same pace. The decomposition rates show a more pronounced migration effect (E) in the SE, especially when comparing the cohorts 1926-30 versus 1931-36.

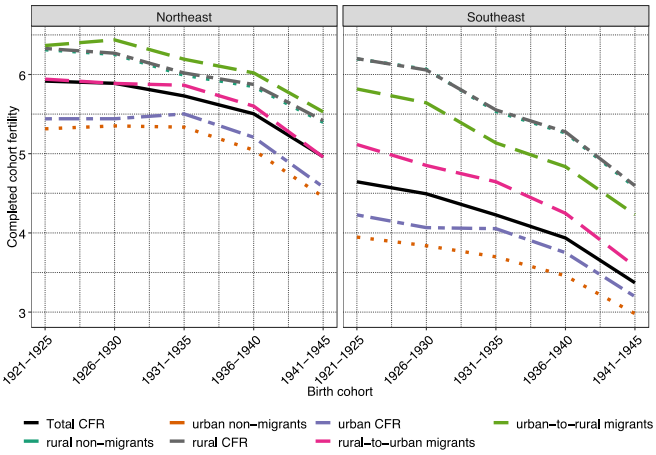



*Fig.1: Cohort Fertility rates from in-migrants and non-migrants, Southeast and Northeast, births cohorts 1921-1945*

**Conclusions.** The rapid decline in fertility in Brazil was primarily marked in urban regions. Then spreading to all parts and social strata, which explains the reduction of differentials across cohorts in both areas, especially after the 1931-1935 cohorts, consistent with the milestone of fertility. It is expected that migration does not have such an effect, considering the beginning of the transition, when other factors such as the introduction of contraceptive methods stood out. This effect is expected to be higher in later cohorts. However, the decomposition of the rates showed that if it were not for rural/urban migration, fertility rates would be 5% higher in the SE and almost 3.5% in the NE. In other words, the migratory effect accelerated the initial pace of the demographic transition.

## References

Lerch, M. (2019). "Regional variations in the rural-urban fertility gradient in the global South." PLoS ONE 14(7): e0219624.

# AI ethics with Chinese characteristics? How the formulations of fairness have evolved with exogenous and endogenous institutional changes in China

Junhua Zhu, University of Turku, Finland
*Email: junzhu@utu.fi*
IIASA Mentors: Wei Liu (POPJUS) and Jenan Irshaid (POPJUS)

**Introduction.** Artificial intelligence (AI) without regulation can trigger a wide array of ethical concerns including but not limited to privacy concern, transparency, and responsibility dilemma. In particular, AI-enabled applications can also reinforce the unfairness in the society, such as discriminatory pricing algorithms and surveillance systems targeting specific ethnic groups. To address these concerns, Chinese tech-giants are undergoing substantial institutional changes both exogenously (government policy changes) and endogenously (enterprise adjustments). In order to understand the Chinese approach of AI governance, this research choosing fairness as the subject of study attempts to elaborate how the formulations of fairness have evolved in different applications scenes (ASs) with institutional changes.

**Methodology.** This research employed semi-structured interview as the major method for data collection. Three AI practitioners who work respectively in three different ASs (I: smart voice assistant in customer service, II: order distribution in food delivery, III: product pricing in e-commerce) were recruited as participants. Interviews were recorded with the consent from the participants, transcribed verbatim, pseudonymised. Via QSR NVivo, the transcriptions were coded and analysed with a deductive thematic analysis, under the fairness formalization framework (FFF) from Gajane and Pechenizkiy (2017).

**Results.** The formulations of fairness vary among different ASs. Furthermore, the formulation fairness may change over time in the same AS. In AS I, fairness is formalized as the same error rate in all social groups, namely the smart voice assistant can understand the mandarin of all users similarly (FFF: *group fairness*). In AS II, fairness was formalized as equal chances for all deliverers to obtain every order on a first-come-first-serve basis (FFF: *equality of opportunity*) and is changing to the formalization that all deliverers from the same company and same region should receive similar amount of orders (FFF: *individual fairness*). In AS III, fairness was formalized as every individual could purchase the same product at their own preferable prices (FFF: *preferred impact*) and has changed to the formalization written in the law that all the users should be able to purchase the same product at the same price (FFF: *counterfactual fairness*).

**Conclusions.** The formulation change in AS II from a free competition-based to an egalitarianism-based reasoning, as well as a switch from a preference-based to a parity-based formulation in AS III, happened around the same time when the government issued a series of regulative policies on AI governance, after which the slogan of "*common prosperity*" revived. These changes can be a result of both the exogenous and endogenous institutional changes (Roland, 2004). The former refers to mainly governmental intervention and the latter includes enterprise repositioning, structural reform, and consideration for sustainable development.

**References**

Gajane P & Pechenizkiy M (2017). On Formalizing Fairness in Prediction with Machine Learning. arXiv:1710.03184v3
Roland G (2004). Understanding institutional change: Fast-moving and slow-moving institutions. *Studies in Comparative International Development*, 38, 109-131.

# *Strategic Initiatives (SI)*

# Coupled dynamics of biodiversity loss and undernutrition in eastern Madagascar: a participatory agent-based model

Romain Clercq-Roques, LSHTM, United Kingdom
*Email: romain.clercq-roques@lshtm.ac.uk*
IIASA Mentors: Katya Perez Guzman (SI), Marta Kozicka (BNR/IBF)

**Introduction.** Undernutrition remains the primary cause of mortality in Madagascar, especially among poor rural communities, dependant on subsistence agriculture and wild foods. Furthermore, Madagascar, a biodiversity hotspot, is registering rapidly diminishing levels of biodiversity, notably due to deforestation and unsustainable wild species harvesting. In fields, soil biodiversity is impacted by intensification of slash & burn practices, decreasing soil fertility and yields. This leads to reduced ecosystem services provided by biodiversity, which in turn increases vulnerability of agricultural production to climatic events and pests. It is possible, that farmers' short-term responses to decreases in agricultural productivity and wild food availability intensifies the use of biodiversity-harmful practices, potentially increasing undernutrition over the longer term. This study aims to explore the current dynamics and compare them to alternative scenarios introducing a package of agroecological practices and/or forest conservation. The specific social and ecological processes linking biodiversity and nutrition will be modelled to assess whether they reproduce the observed patterns of biodiversity loss and undernutrition, suggesting that coupled social-ecological dynamics could drive undernutrition.

**Method.** An abstracted agent-based model was developed in Netlogo based on interviews and role-playing games with local experts and farmers as well as academic literature, to test whether the observed dynamics of biodiversity loss and undernutrition emerge from individual farmer land-use decisions in a changing environment, and changes in ecosystem services. The model also introduced a package of agroecological practices and forest conservation to assess their ability to improve biodiversity and nutrition outcomes. The model includes two types of agents: farming households, and land patches on a 2 dimensions space. Farmers appropriate patches to produce food, thus changing their biodiversity variables and landscape forest cover. Farmers also forage in forest, impacting wild edible species levels. Stochastic disruptions represent varying harvest losses due to climatic events and pest pressure. The model simulates population growth and the adaptation of farmers to increasing land scarcity and changes in nutritional outcomes, over 150 annual time steps.

**Preliminary results.** In the model, while the slash and burn practices initially maintained adequate biodiversity and nutritional levels, increasing population density led to their collapse, as land scarcity forced farmers to completely remove the forest cover then to switch to a strategy of unsustainable intensification of slash & burn, degrading soils and ecosystem services until the landscape becomes completely unproductive. Deforestation and increasing wild species harvesting led to their extirpation, reducing diet diversity and leaving farmers vulnerable to dwindling yields and higher harvest losses. Introducing a package of agroecological practices ensured sustainably high biodiversity and nutrition outcomes, as they required less area, maintained soil biodiversity and associated agrobiodiversity in fields, increased production diversity, and improved both energy and micronutrient intakes. Maintaining forest cover reduced harvest losses from climatic events and pests but also reduced surface available for agricultural production, generating trade-offs. Implemented on its own, protecting forested areas led to greater pressure on wild species and their extirpation, as farmer attempted to compensate lower agricultural production. Introducing foraging quotas protected wild species but did not appear to provide notable nutritional benefits, as harvested amounts were insufficient for a growing population.

**Conclusions.** The model reproduced empirical patterns of increasing deforestation, extirpation of wild species, soil degradation and decrease in agricultural production and wild food availability, leading to insufficient energy and micronutrient intakes. The package of agroecological practices showed large biodiversity and nutritional co-benefits, providing both adequate energy and micronutrients intakes. Forest conservation generated trade-offs and will require careful parameterisation and validation to guide action. The model will be further parameterised and iteratively developed with local stakeholders.

*Index*

Alessandro Taberna ..... 18
Andreas Lichtenberger ..... 47
Aniruddha Deshpande ..... 13
Camila Ferreira Soares ..... 56
Chayasmita Deka ..... 12
Christopher M. Wade ..... 33
Cindy Azuero Pedraza ..... 21
Dan Wang ..... 34
Dapeng Feng ..... 25
Dipesh Chapagain ..... 10
Gemma Gerber ..... 15
Gesangyangji ..... 45
Hyun-Woo Jo ..... 29
Irlan A. Rum ..... 31
Jan Streeck ..... 44
Junhua Zhu ..... 57
Laura Merz ..... 16
Leonard Kwhang-Gil Lemke ..... 53
Lilipramawanty K. Liwin ..... 55
Linda Ofori ..... 17
Maddalena Muttoni ..... 48
Marlene Palka ..... 30
Mathilde de Goër de Herve ..... 50
Mel George ..... 38
Melissa Chapman ..... 24
Minwoo Park ..... 42
Nora Krenmayr ..... 39
Olivia Becher ..... 22
Osamu Nishiura ..... 41
Pietro Andreoni ..... 9
Pooja Ramamurthi ..... 43
Prerita Agarwal ..... 36
Romain Clercq-Roques ..... 59
Sebastian Franz ..... 37
Simon Happersberger ..... 26
Sophie Erfurth ..... 14
Swaptik Chowdhury ..... 11
Tara Ippolito ..... 28
Thomas G. Leffler ..... 52
Tianyang Lei ..... 40
Wei Xie ..... 19
Wenjia Cai ..... 23
Xander Huggins ..... 27
Xinyi Kou ..... 51
Xueting Li ..... 54
Zhimin Shi ..... 32