YSSP

Young Scientists Summer Program

Proceedings of the YSSP Final Colloquium 2019

International Institute for Applied Systems Analysis
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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, 22–23 August 2019.

The Proceedings are the sole work of the authors with limited or no review by their IIASA supervisors 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 They are not for publication in the current form.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: Jakob Knauf, Simone Pretorius, Jun Ukita Shepard, and Brian Fath

Contents

Air Quality and Greenhouse Gases 8

Advanced Systems Analysis 13

Energy 20

Ecosystems Services and Management 28

World Population 42

Risk and Resilience 48

Transitions to New Technologies 55

Water 59

Thursday, 22 August 2019						
9:00 – 9:10	**Welcome and Introduction by YSSP Dean JoAnne Bayer (Wodak Room)**					
	WODAK Room			**GVISHIANI Room**		
Day 1 - Session 1	**Input Output Models** Chair: Nikita Strelkovsky (ASA)			**Carbon Stocks and Emissions** Chair: Peter Rafaj (AIR)		
09:10 – 09:35	Hanspeter Wieland	ASA	Assessing the robustness of global iron & steel supply chains over time (1995–2015) to identify vulnerability hotspots in trade networks	Carlos Andrés García Velásquez	ESM	Environmental concerns of the use of biomass for bioplastics production and its consequences in the economic performance
09:35 – 10:00	Stefanie Klose	ENE	Understanding the impacts of biophysical constraints on IAM results – linking a bottom-up demand-side model and the message model: The case of copper	Manan Bhan	ESM	Do more trees mean more carbon? How land use disturbs the tree cover – carbon stock correlation in the tropics
10:00 – 10:25	Bertram de Boer	ESM	Renewable Energy Directive (RED II)'s contribution to employment and GDP growth	Jhonny Villarroel – Schneider	AIR	Combined energy solutions to improve energy self-sufficiency and reduce GHG emissions in Latin America's dairy sector
10:25 – 10:45 BREAK						
Day 1 - Session 2	**Building Energy Use** Chair: Alessio Mastrucci (ENE)			**Urban Complexity** Chair: Marlene Palka (RISK)		
10:45 – 11:10	Xu Wang	AIR	Assessing co-benefits of energy efficient air conditioners in Chinese residential building sector	Safa Fanaian	RISK	Rivers and cities: Exploring their complex water-risk and its governance
11:10 – 11:35	Aishwarya Iyer	ENE	Indian residential buildings: Future growth and energy impacts	Daniel Johnson	ESM	Mitigation of the urban heat island effect: An economic assessment of the potential of green infrastructure
11:35 – 12:00	Alexandra Nutkiewicz	ENE	Characterization of urban informal settlements in the developing world: Assessing key design parameters to improve thermal comfort and building energy consumption	Regina Buono	RISK	Structuring emergence: How does law impact the emergence frontier for nature-based solutions to enhance urban resilience?
12:00 – 13:30 BREAK						

Thursday, 22 August 2019						
	WODAK Room			**GVISHIANI Room**		
Day 1 - Session 3	**Migration** Chair: Sonia Spitzer (POP)			**Transportation Efficiencies and Technologies** Chair: Charlie Wilson (TNT)		
13:30 – 13:55	Nicolas Choquette-Levy	ASA	The role of agricultural networks and climate adaptation strategies in rural-urban migration	Wu Chen	TNT	Unlocking the transportation-energy nexus: Case study for China's passenger vehicles transition
13:55 – 14:20	Amr Abdelwahed	POP	Young people's migration intention in Egypt	Jun Ukita Shepard	ENE	A representation of transportation and trade networks in global energy models
14:20 – 14:45	Hélène Benveniste	POP	Unpacking repercussions of international migration assumptions in the population component of SSP scenarios onto their GDP, inequality and emissions components	Minghao Qiu	AIR	Identification of high-emitting vehicles only need a few snapshot measurements
14:45 – 15:00 **BREAK**						
Day 1 - Session 4	**Bioenergy and Electricity Technologies** Chair: Sylvain Leduc (ESM)			**Air Impacts.COM** Chair: Gregor Kiesewetter (AIR)		
15:00 – 15:25	Hoang Anh Tran	ESM	Policy-relevant simulations on co-firing biomass for electricity in Vietnam	Muye Ru	AIR	Integrating the morbidity burden and its economic impacts into air quality policies
15:25 – 15:50	Fabian Stenzel	WAT	Do irrigated bioenergy plantations have a larger effect on water stress than the avoided climate change?	Asya Dimitrova	POP	Health co-benefits of air quality improvements in India under climate change mitigation and air quality abatement policies
15:50 – 16:05	Jakob Knauf	TNT	Using district heating for storing renewable excess electricity in an 80% demand reduction scenario	Luiza Toledo	COM	From Science to #SciComm: Sharing science in the world of hashtags
16:15 – 16:30 **BREAK**						

Thursday, 22 August 2019						
	WODAK Room			**GVISHIANI ROOM**		
Day 1 - Session 5	**Learning Methods and Cognition** Chair: Piotr Zebrowski (ASA)			**Biodiversity** Chair: Piero Visconti (ESM)		
16:30 – 16:55	Brent Eldridge	ASA	A learning algorithm to estimate self-commitment inefficiencies in electricity markets	Gabriel R. Smith	ESM	Ecosystem effects of boreal N-fixation by bryophytes
16:55 – 17:20	Paolo Miguel Manalang Vicerra	POP	Cognitive, physical, and mental functioning: a structural equation approach	Yuyoung Choi	ESM	Assessing synergies and trade-offs between biodiversity conservation and carbon stock under climate change in South Korea

Friday, 23 August 2019						
9:00 – 9:10	**Welcome and Introduction by YSSP Scientific Coordinator Brian Fath (Wodak Room)**					
	WODAK Room			**GVISHIANI Room**		
Day 2 - Session 1	**Stock Flow Models** Chair: Bas van Ruijven (ENE)			**Sustainable Agriculture** Chair: Tamás Krisztin (ESM)		
09:10 – 09:35	Christine Hung	ENE	Coupling lifecycle assessment, vintage stock models and IAMS: Prescribing policy for the sustainable transport electrification pathways	Julian Joseph	ESM	Agricultural productivity and FDI in land in sub - Saharan Africa: A regional econometric approach
09:35 – 10:00	Nepomuk Dunz	RISK	Unilateral climate policies in a North-South Stock-Flow Consistent model	Zitong Liu	ESM	Model based approach for managing nitrogen for sustainable wheat-maize rotation
10:00 – 10:25	Chenling Fu	ASA	Material flow-stock network model of urban metabolism—an application in the global megacity Beijing	Matthew Gibson	ENE	Energy-food-health nexus of grain supply losses in India
10:25 – 10:45 BREAK						
Day 2 - Session 2	**Probabilities and Games** Chair: Stefan Hochrainer (RISK)			**Integrated Assessment Models** Chair: Brian Fath (ASA)		
10:45 – 11:10	Christopher Krapu	ASA	Assessment and probabilistic forecasts of cropland loss due to lake expansion in the North American interior	Talita Cruz	ENE	Modelling social heterogeneity in integrated assessment models (IAMS): how a better representation of income inequality affects mitigation potentials in Brazil
11:10 – 11:35	Yoga Wienda Pratama	ESM	Energy system planning with endogenous fuel price: A bilevel game after the Paris Agreement	Bruno Meirelles de Oliveira	RISK	Prototype of social-ecological systems resilience using system dynamics modelling
11:35 – 12:00	Huan Liu	RISK	Estimation of business lifeline resilience factors to disaster: a Markov model analysis of multiple lifeline disruptions	Fortune Gomo	WAT	Evaluating irrigation development under environmental change taking into consideration water-energy-food nexus interactions: Case of Malawi
12:00 – 13:30 BREAK						

Friday, 23 August 2019						
	WODAK Room			**GVISHIANI Room**		
Day 2 - Session 3	**Land Use Impacts** Chair: Ian McCallum (ESM)			**Drought** Chair: Sylvia Tramberend (WAT)		
13:30 – 13:55	Katharina Schulze	ESM	Improving evidence-based modelling of global forest management patterns	Felicia Chiang	WAT	Concurrent temperature and precipitation shifts in historical and historical natural-only model simulations
13:55 – 14:20	Rory Gibb	ESM	Accounting for land use and climate change uncertainty in projections of zoonotic disease under global change: a case study of Lassa fever in West Africa	Simone Pretorius	RISK	Examining the lessons learnt from the 2015-2018 drought on large-scale commercial farmers, in the winter rainfall region of the Western Cape, South Africa
14:20 – 14:45	Lilit Ovsepyan	ESM	Environmental benefits related to carbon sequestration after land use change	Yang	WAT	Evaluation of groundwater recovery in the North China plain using the high-resolution Community Water Model
14:45 – 15:00 **BREAK**						
Day 2 - Session 4	**Agent Based Models** Chair: Charlie Wilson (TNT)			**Health and Well-being** Chair: Jeofrey Abalos (POP)		
15:00 – 15:25	Roope Kaaronen	ASA	The cultural evolution of sustainable behavior: An agent-based modelling approach	Moradhvaj	POP	Education or economic status? Comparing their relative effect on adult health and mortality in India using longitudinal survey
15:25 – 15:50	Xingrong Zhao	TNT	Analysis of electric vehicle adoption in Shanghai based on empirical data and agent-based simulation	Paul Joseph Ruess	WAT	Trade openness and the groundwater use and depletion of nations
END OF COLLOQUIUM **RECEPTION IN CONFERENCE AREA**						

Air Quality and Greenhouse Gases (AIR)

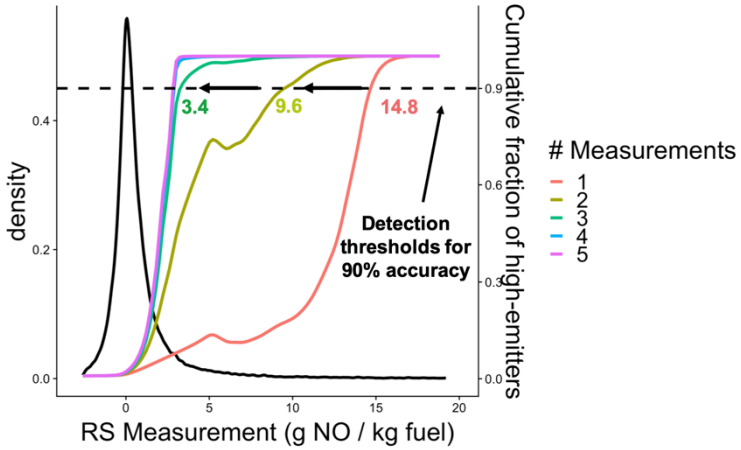
Identification of high-emitting vehicles only needs a few snapshot measurements

Minghao Qiu, Massachusetts Institute of Technology, USA
Email: mhqiu@mit.edu
IIASA Supervisor: Jens Borken-Kleefeld (AIR)

Introduction. Is it possible to understand the emission behaviour of a vehicle based on just a few instantaneous measurements? The idea to identify high-emitting vehicles in the fleet while they pass an emission measurement device placed at the roadside is of great interest to policy makers – and if possible could greatly reduce the pollution load. Despite the strong interests from the policy makers, no rigorous investigation exists on how to use instantaneous emission records to robustly identify those vehicles with excessively high emissions. Our work, for the first time, directly establishes the link between the instantaneous emissions and mean emissions, demonstrates how much repeated measurements of the same vehicle improve the accuracy of the identification and investigates the influence of the threshold value used.

Methodology. We start from a large dataset of instantaneous vehicle emissions measured by the remote sensing devices in Europe, from 2011 to 2016. We view these instantaneous emissions measured as the composition of the mean vehicle emission, that we are eventually interested in, and some instantaneous fluctuation around the mean values. We derive proxy distributions of these instantaneous fluctuations from measurements of some two dozen cars driven for several hours each. We develop the method at the example of NO emissions from gasoline cars certified to the Euro 4 emission standard.

Fig 1: detection thresholds under repeated measurements



Results. With our new approach we estimate that less than 4% of the gasoline Euro 4 cars measured outside Zurich and 15% to 22% of the respective cars measured in London emit three times or more of the NO emission limit. Removing those vehicles could reduce NO emissions from the gasoline Euro 4 cars by up to 35% in Switzerland and by as much as 68% in London. Trying to identify such high-emitting vehicles with just a single instantaneous remote measurement would not yield a good accuracy. However, repeated measurements significantly increase detection accuracy and overcome the inherent ignorance about the underlying instantaneous fluctuations - the detection threshold (e.g. 90% detection accuracy) can become much more stringent under repeated measurements (see fig. 1). In consequence, enforcement agents could identify almost all high-emitting vehicles with high certainty based on three to four snapshot measurements only. Using an extremely high detection threshold based on single snapshot only let pass more than every second high-emitter. The results are robust for different assumptions on the instantaneous fluctuations.

Conclusions. We develop a method to overcome the large uncertainty in using remote sensing measurements for high-emitter identification. We show that with only four instantaneous measurements of each vehicle it is possible to identify almost all high-emitters with high accuracy. Removing their emissions could be very effective to reduce pollution levels without encumbering the ordinary driver.

Integrating the morbidity burden and its economic impacts into air quality policies in Asia

Muye Ru, Duke University, USA
Email: muye.ru@duke.edu
IIASA supervisors: Gregor Kiesewetter (AIR), Fabian Wagner (AIR)

Introduction. Human health impacts from fine particulate matter ($PM_{2.5}$) pollution causes substantial morbidity burdens, such as loss of productivity due to various fatal and non-fatal diseases, demand for social and household care, and medical costs. These morbidity impacts are directly associated with market impacts. Previous evaluations of these morbidity burdens and costs are limited and based mostly on evidence from some high-income countries. Comprehensive estimates of the morbidity burden and cost accounting for Asian countries are still lacking. However, these can be especially important for Asian countries, where $PM_{2.5}$ exposures are high, and the socioeconomic development is dynamic. From the policy prospective, it is important for Asian countries to understand the morbidity impacts and the associated economic costs from ambient $PM_{2.5}$ pollution.

Methodology. We therefore produce morbidity and cost estimates for Asian countries, based on a systematic review of data and literature. To obtain a comprehensive estimate of the morbidity burdens, we study both fatal diseases and non-fatal impacts. For fatal diseases shown to be related with $PM_{2.5}$, we estimate years lost due to disability (YLD). For non-fatal diseases, we estimate the prevalence of children asthma and chronic bronchitis of children and adults respectively, using concentration-response functions obtained from the meta-analysis. We estimate the total number of lost work days, restricted work days, and hospital admissions due to cardiovascular and respiratory diseases respectively. These morbidity endpoints are linked to a country-level matrix of unit societal costs. Unit costs for each disease are obtained from a meta-analysis of cost of illness (CoI) studies, while unit costs for the labor costs are derived from the average wages for each country. The form of market costs we assess include the loss of labor productivity, medical expenditures, and the cost of social and family care. We apply the country-level morbidity and economic costs to air pollution projection scenarios developed with the GAINS-ASIA model, and compare to the cost of air pollution measures.

Results. The total morbidity burden associated with ambient air pollution incurs 1.0% total GDP loss of Asian countries from medical expenditures and care cost, and 0.5% total GDP loss from lost labor. On country level, these losses span from 1-4% of country's GDP for medical expenditures and care cost, and 0-3% for labor loss. In total, the loss from morbidity costs reaches 2.1% (0.2-7.3%) of GDP for Asian countries, contrasting 0.5% in OECD countries (OECD, 2017). The 2.1% average morbidity loss also exceeds the air pollution control cost of 1% of GDP in 2015.

Conclusions. Based on our systematic review, the morbidity burden of air pollution in Asia is shown to be substantial. Medical and care costs attributable to ambient air pollution are approximately equivalent to the control cost of air pollution in 2015. Moreover, cost from labor loss causes additional 0.5% of GDP loss in Asia. The total morbidity cost in Asia reaches 2.1% of GDP, quadrupling the morbidity cost in OECD countries. These results highlight the cost-effectiveness of air pollution control in Asia.

References

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Combined energy solutions to improve energy self-sufficiency and reduce GHG emissions in Latin America's dairy sector

Jhonny Villarroel-Schneider, KTH Royal Institute of Technology, Sweden
Email: jhonnyvs@kth.se
IIASA Supervisors: Lena Höglund Isaksson (AIR) and Adriana Gomez Sanabria (AIR)

Introduction. The demand for energy services in the Latin American (LA) dairy sector is increasing proportionally to a 2.9% annual growth in production (during the years 2005 to 2015). This demand is mostly met by fossil fuel-based services without considering a proper manure management that could include the production and utilization of biogas in dairy farms[1]. In this scenario, we assess the potential for biogas-based solutions, which apart from supplying various energy services (gas for cooking, electricity, refrigeration, heating), can reduce methane emissions from manure management and avoid CO_2 emissions associated with the use of fossil fuel-based services[2]. We determine whether the potential for biogas production is large enough for the dairy sector to be self-sufficient in terms of energy services and quantify the potential savings in GHG emissions.

Methodology. To perform this study the following steps were followed: data collection from the Greenhouse Gas – Air Pollution Interactions and Synergies (GAINS) model[3] (number of dairy cows, manure management, size of farms for the year 2015) and from literature, estimation of biogas production (considering country specific data, i.e. cow's excretion rate, biogas yield factor, collection of manure rate), estimation of energy services demand for the dairy sector (electricity, refrigeration, hot water and gas for cooking),design of biogas-based solutions for the supply of energy services (considering farm size and efficiencies of the technologies), demand-supply analysis of energy services required, and quantification of CH_4 and CO_2 emissions reduced (using emission factors for each country).

Preliminary Results. Results indicate that biogas produced in LA dairy sector would be enough to cover their own energy services demand. The biogas-based solutions proposed allows supplying: (i) gas for cooking/ heating-water and a surplus of biogas for farms with less than 50 dairy cows; (ii) gas for cooking/heating-water, electricity for refrigeration/equipment, and a surplus of electricity for farms with 50 to 100 cows; (iii) gas for cooking and for the production of electricity/heat in combined energy systems for farms with more than 100 cows. For the latter farm size, the recovered heat is used for the provision of hot water and refrigeration while a surplus of electricity and heat is generated. Reduction in CH_4 emissions reaches up to 5% of the total CH_4 emissions from the agricultural sector while the total CO_2 eq. emissions savings (when applying the solutions) goes up to 2% of the total GHG emissions from all sectors, this is for the countries in LA with the highest reduction potential (for the year 2015).

Conclusions. We find that for small farms, where the provision of refrigeration and electricity (assuming economic limitations) is not considered feasible, there will be an excess of biogas produced. In this case, the application of centralized solutions to supply energy services can be an alternative, considering existing dairy cooperatives/associations in most of LA countries. For medium and large farms, we find the biogas potential enough to support energy self-sufficiency which includes a surplus of electricity that can be sold to the grid. Apart from the potential of GHG emissions reductions, these solutions promote an efficient use of the energy resources. At a country level, the results can help to consider policies that support the implementation of these solutions in dairy farms with high potential to be self-sufficient in terms of energy services. Finally, these solutions can be incorporated as control strategies in the GAINS model considering the interactions with the energy sector.

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Assessing co-benefits of energy efficient air conditioners in Chinese residential building sector

Xu Wang, Beihang University, School of Economics and Management, China
Email: wngxu@buaa.edu.cn
IIASA Supervisor: Pallav Purohit (AIR), Shaohui Zhang (AIR)

Introduction: The global energy consumption for space cooling is growing faster than for any other end use in building sector, due to urbanization, population and economic growth in developing countries. In China, the ownership of room air conditioners (ACs) is growing at an alarming rate, which is bound to bring several challenges such as the increase of electricity consumption and the associated emissions of greenhouse gases (GHGs) and air pollutants. The Kigali Amendment (KA) to the Montreal Protocol protects the climate by phasing down high GWP hydrofluorocarbons (HFCs), commonly used as refrigerants, which will catalyse additional improvement in energy efficiency of ACs. We assess co-benefits of efficient ACs (EACs) in China along with transition towards low-GWP refrigerants under the baseline and alternative scenarios.

Methodology: In this study, a bottom-up model is developed for the penetration of ACs and assess the potential for energy saving and associated mitigation of GHGs and air pollutants in Chinese residential sector at the provincial scale with urban and rural characteristics. ACs ownership is modelled for different provinces using household income and cooling degree day (CDDs) in a business-as-usual (BAU) scenario. We assess four alternative scenarios to explore different possible futures under different EAC promotion trends. The first two only consider direct impact brought by ACs' system efficiency improvement: EAC(E) with economic energy efficiency potential and EAC(T) with technical energy efficiency potential whereas the last two scenarios consider both: system efficiency improvement and the efficiency improvement due to the transition towards low-GWP refrigerants under the KA: EAC(E)+KA and EAC(T)+KA. To assess emission reduction in the alternative scenarios we have used three variants of implied emission factors from IEA/WEO 2018 scenario: current policies, new policies and sustainable development scenarios.

Results: The number of ACs in China will reach 997 million in 2030 and 1114 million in 2050 as compared to 568 million in 2015 (as shown in Figure 1.a). The penetration rate of ACs in 11 provinces and municipalities will exceed 250%, most of which are in the southern hot region of China; while penetration rate of four western cold region of China will be less than 50%. The electricity consumption for ACs in China will reach 1314 TWh in 2050 as compared to 503 TWh in 2015 under the BAU scenario. Moreover, in 2050, under EAC(T)+KA scenario, the energy saving potential is estimated at 550 TWh and GHG mitigation potential is assessed at 697 Mt CO_2eq (as shown in Figure 1.b), which is equivalent to 8.3% total energy consumption and 27.1% total GHG emissions of Chinese building sector in 2015.

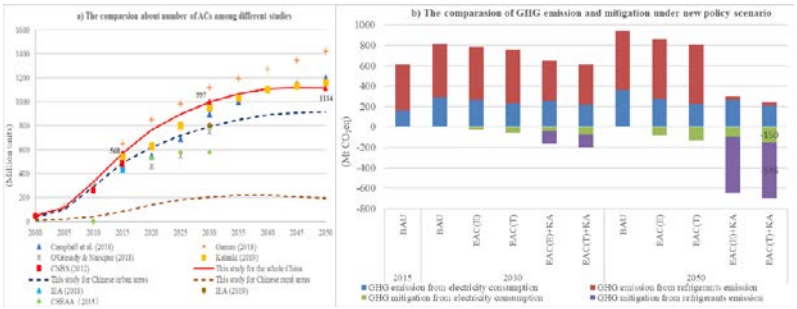


Figure 1. The comparisons about number of ACs and GHG mitigation: a) the comparison about number of ACs among different studies; b) the comparisons of GHG mitigation under new policy scenario.

Conclusions: Tracking energy-efficiency opportunities is in China's self-interest, and the adoption of appropriate domestic policies can help achieve and accelerate the transition to low-GWP alternatives, along with the ultimate goal as building a low-carbon and energy saving society in China. Our results indicate that EACs with low GWP refrigerants could reduce 7.75% and 27.1% of Chinese buildings GHG emission in 2030 and 2050, respectively.

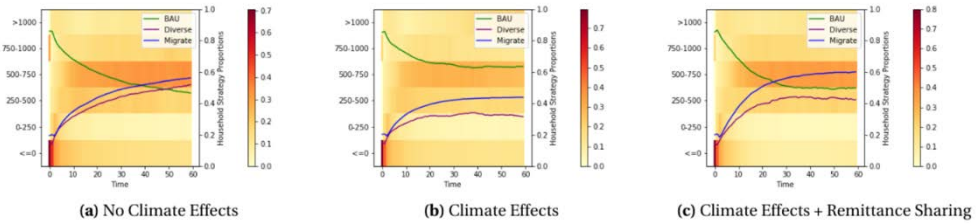
Advanced Systems Analysis (ASA)

The impact of risk-sharing mechanisms on farmer climate adaptation strategies

Nicolas Choquette-Levy, Princeton University, USA
Email: nc8@princeton.edu
IIASA Supervisors: Matthias Wildemeersch (ASA), JoAnne Linnerooth-Bayer (RISK), Wolfgang Lutz (POP)

Introduction. Climate change poses significant risks to smallholder farmers' livelihoods, with consequences for several policy issues. In particular, previous studies identified correlations between higher temperatures, decreasing crop yields, and changing human migration flows [1-2]. However, the role of migration in the context of other adaptation strategies is still poorly understood. This project investigates the impact of climate effects and risk-sharing networks on the use of migration as an adaptation strategy in subsistence farming communities.

Methods. We develop a stylized agent-based model (ABM) consisting of smallholder farmer households with heterogeneous risk preferences, wealth, and social capital. The ABM models the impact of interactions between households on the adoption of different adaptation options, e.g. migration and crop diversification, as climate stress increasingly threatens farming livelihoods via higher temperatures and extreme drought. The model is calibrated using climate and socioeconomic data from South Asian subsistence farming regions. We also develop a scenario in which migrants share a portion of their remittances with other households as a way to diversify livelihood risks.



(a) No Climate Effects **(b)** Climate Effects **(c)** Climate Effects + Remittance Sharing

Figure 1. Distribution of household strategy choices (right axis) and perception of migration payoffs (left axis).

Results. Without climate effects, approximately 60 percent of households engage in migration over a 30-year timeframe (Fig. 1a; each time step represents 6 months). Migration increases community income through remittances and finances a transition to cash crops for approximately 55 percent of households. However, only 45 and 30 percent of households engage in migration and crop diversification, respectively, when we include climate effects (Fig. 1b). As climate increasingly impacts farming-based livelihoods, fewer households have the financial ability to afford migration and diversification strategies. This restricts information exchange between households about alternative strategies (colormaps in Fig. 1), which further "traps" households in subsistence farming. Allowing for moderate remittance sharing within household networks (25 percent of total remittances) substantially increases the proportion of households who can migrate, though adoption of crop diversification remains lower (Fig. 1c).

Conclusions. The initial results from our model are consistent with previously-highlighted concerns that substantial climate change may contribute to "trapping" poor populations in place [3]. Informal risk-sharing mechanisms improve the uptake of migration, but still appear insufficient to incentivize crop diversification. As a next step, we plan to explore the interaction of formal and informal risk-sharing mechanisms on community outcomes.

References

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Market design evaluation of offer incentives and efficiency in electricity markets

Brent Eldridge, Johns Hopkins University, Baltimore, USA
Email: breldridge@gmail.com
IIASA Supervisor: Elena Rovenskaya (ASA)

Introduction. Most electricity in the United States is produced and priced in centralized auctions run by Independent System Operators (ISOs). Each day, the ISO receives bids from market participants and then follows a two-step process: first determining a production schedule and then calculating uniform market clearing prices. The production schedule maximizes social welfare assuming that the participants offer truthfully. Because power production costs are typically non-convex, this incentive compatibility cannot be guaranteed. Most ISO pricing rules are nonetheless based on properties that assume a social optimum has been obtained, but to not address how or whether this optimum can be found in a market with self-interested participants. We show that a so-called "dispatchable" pricing rule often attains a social optimum while two more commonly used pricing rules do not.

Methodology. We propose a method to evaluate the efficiency of ISO pricing rules with a numerical market simulation. Participant offers are simulated using reinforcement learning algorithms to model "self-commitment" decisions by profit-maximizing bidders. A bidder self-commits by offering a portion of its production capacity at zero cost to the market, which can sometimes lead to better prices or more production for that bidder's resources. Bidders learn to maximize their outcome for two common pricing rules, "dispatchable" and "restricted", and a hybrid called "partial dispatchable". After the simulated bidder offers reach steady state, the pricing rule's effect on market efficiency is evaluated by comparing to a social optimum.

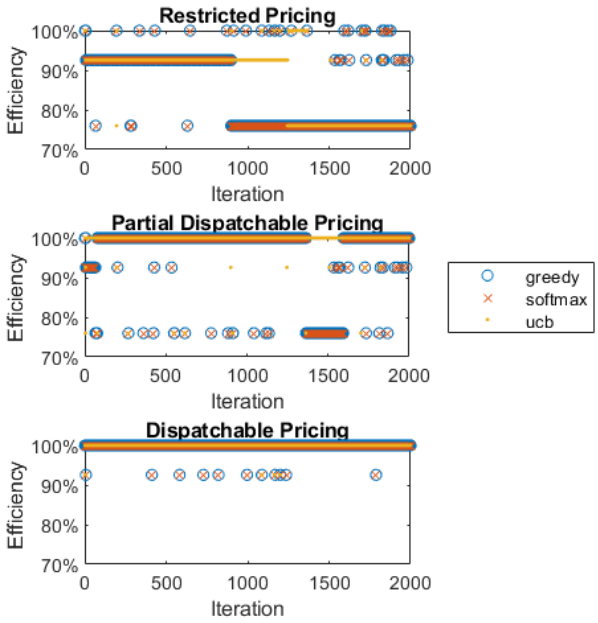


Figure 1: Simulated market efficiency results for three pricing rules using various learning algorithms (Greedy, SoftMax, and UCB). Strategic bidding incentives lead to significant losses for the first two pricing rules, but the dispatchable pricing rule achieves close to perfect market efficiency.

Results. Simulated bidders were able to identify profitable self-commitment opportunities in market designs with the restricted or partially dispatchable pricing rules. Although the self-commitments increased profits of individual bidders, the resulting schedule reduced market efficiency by shifting energy production to more expensive resources. In one test case, shown in Figure 1, the restricted pricing rule incentivizes self-commitments that reduce market efficiency by nearly 25%. In another test case, the learning algorithms identify a strategy that manipulates network constraints and causes a 5% market efficiency loss. In addition to experimental results, we also offer a theoretical explanation for why these results are pertinent to ISO markets. Incentive compatibility cannot be guaranteed because the nonconvexities in these markets preclude the existence of a perfect Bayesian Nash equilibrium (PBNE). However, our experimental results indicate that a near-Nash equilibrium, a relaxed PBNE, may provide enough incentive for market participants to bid truthfully.

Conclusions. This project simulates self-commitment behavior that is commonly observed in actual ISO markets. Our results show that the restricted pricing rule, commonly used in all ISOs, can incentivize self-commitments that increase bidder profits but reduce market efficiency. Some ISOs have begun to adopt pricing rules similar to the partial dispatchable rule, but this also results in significant inefficiencies. The dispatchable pricing rule, in contrast, removed the adverse incentives and resulted in near perfect market efficiency in each test case. Although results are only given for small examples, we offer a theoretical explanation for why similar results should be expected even in more realistic scenarios.

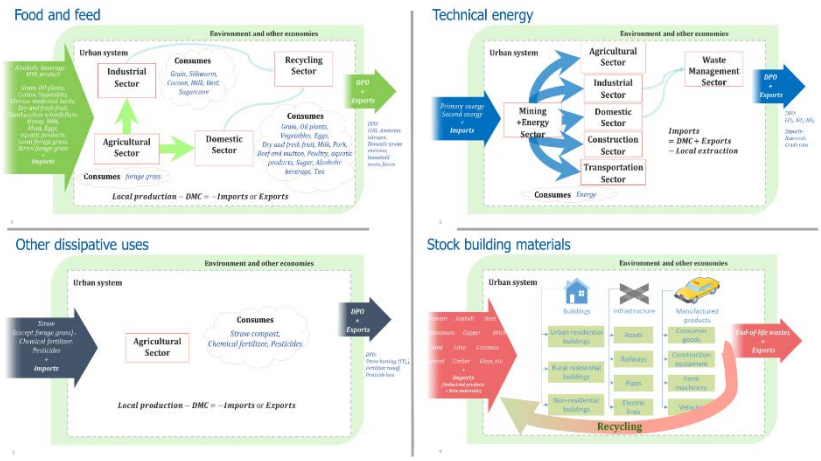
Material flow-stock network model of urban metabolism system—an application in the global megacity Beijing

Chenling Fu, Beijing Normal University, China
Email: fclhappy@163.com
IIASA Supervisor: Brian Fath (ASA)

Introduction. Cities consume most of the world's natural resources, of which over one-half is stock materials, which are processed and manufactured to provide services for human benefits. After entering an urban system, various materials are consumed and used by different sectors, some of them are recycled and some of them are directly discharged into the environment as pollutants. The perspective of urban metabolism is a bridge connecting resource consumption with pollutant and transformation process. The network perspective can elaborate urban metabolism process. Monitoring urban network metabolic process is crucial to urban resource management. Existing research on flow-stock metabolism is rough and not detailed to the sector, while the network research on a sector scale often focuses on flows and ignores the important role of stocks.

Methodology. In this study, a Material Flow-Stock Network (MFSN) model based on urban metabolic perspective was established and applied to Beijing, a global mega-city. All the materials circulating in the urban system are divided into four categories: 1) food and feed, 2) energy, 3) other dissipative materials, and 4) stock building materials. The whole system is divided into: 1) environment and other economies outside the urban system, and 2) agriculture, mining, industry, domestic industry, energy, transportation, construction, waste management industry within the urban system. We used bottom-up material flow analysis to calculate the flow and stock of each sector and their transformation among different sectors. The methods allow one to identify exactly how much flow translates into stocks accumulated in urban systems, and how they flow and accumulate among sectors. Based on them, we use System Robustness to evaluate the stability of the system, thus identifying the critical material and sector that affects the metabolic process of urban system.

Results and Conclusions. The whole process of material input, transformation, output and circulation of urban system is quite complicated and this process is even differs from materials. Thus we built the MFSN model from both the materials and sectors level. Our model is detailed and can solve the most difficult part—transformation of stock building materials. According to three equations that calculate net addition to stock, we clarify the relationships among in-use stock, gross addition to stock, removal from stock, which we found are the key connects flows and stocks in urban system. As result shows, from 2000 to 2015, stock building materials accounts for > 70% in Beijing. We can further divide it into non-metallic mineral, metallic mineral and industrial products in order of proportion. Technical energy was the largest part of dissipasive materials and obviously expanded from 2003 to 2010. From the sector perspective, construction, transportation, and industrial sectors are the main sectors in Beijing, which is connected to the large demand of stock building materials for manufacturing in-use stocks of buildings, infrastructure and manufactured products in Beijing. Specifically, urban residential building, non-residential building and roads were the top 3 in-use stock and experienced “S-type” rise during the research period.



Cultural evolution of sustainable behaviours: Pro-environmental tipping points in an agent-based model

Roope Kaaronen, University of Helsinki, Helsinki Institute of Sustainability Science, Finland
Email: roope.kaaronen@helsinki.fi
IIASA Supervisor: Nikita Strelkovskii (ASA)

Introduction. To reach sustainability transitions, we must learn to leverage social systems into tipping points, where societies exhibit positive feedback loops in the adoption of sustainable behavioural or cultural traits. We employ an agent-based model to study the emergence of social tipping points through five factors which have been previously identified to constitute an ecological approach to human behaviour. These are 1. affordances (action opportunities provided to an organism by the physical environment), 2. asocial learning and habituation, 3. personal states (such as intentions, attitudes and habits), 4. cultural niche construction and 5. social learning in a social network.

Methodology. We use an agent-based model (NetLogo) to model the emergence of pro-environmental behaviours in a landscape of affordances, in a highly clustered and scale-free Klemm-Eguíluz network. We study how various parameters of the model affect its output (proportion of pro-environmental behaviour) and analyse time-series data of the cultural evolution of pro-environmental habits. We empirically validate the model against real-world data of the adoption of cycling and driving behaviours in Copenhagen. We use R for data-analysis and conduct rigorous sensitivity testing with both local (OFAT) and global (Latin-hypercube) sensitivity analysis.

Results. Our model suggests that the introduction of pro-environmental affordances to a social system can have non-linear, self-reinforcing, effects on the emergence of pro-environmental behaviour patterns (see Figure). Our model can reproduce real-world macro-level patterns (cycling in Copenhagen). The structure of affordances in the landscape is identified as the most robust leverage point to the system.

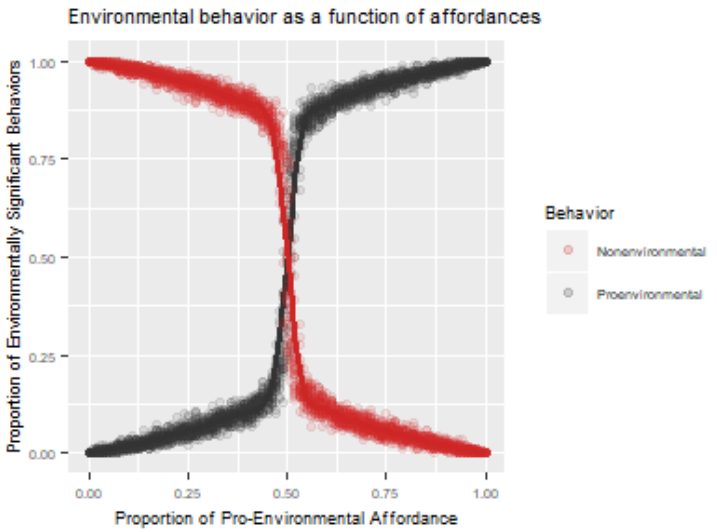


Figure: The nonlinear effect of pro-environmental affordances on the uptake of pro-environmental behaviours (black) and environmentally harmful behaviours (red) in our stylised model run. Each point is the proportion of behaviour at the final step of a model run. This plot includes a total of 3030 simulations, where the initial proportion of pro-environmental affordances is varied from 0 to 1. Notice the phase transition, or tipping-point, when the proportion of pro-environmental affordances is larger or smaller than approximately 0.5.

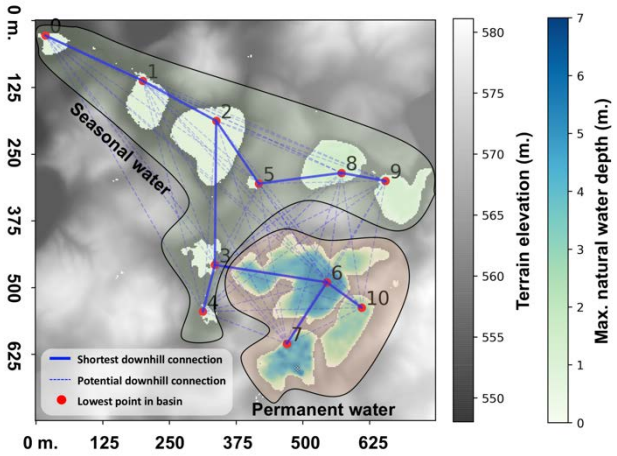
Conclusions. Our model shows how increases in pro-environmental affordances can have nonlinear and robust positive effects on the uptake of pro-environmental behaviours, giving further evidence and justification for (urban) policies that make pro-environmental behaviour psychologically salient, easy and the path of least resistance.

Optimal management of surface drainage networks for agricultural water management

Chris Krapu, Duke University, USA
Email: Christopher.krapu@duke.edu
IIASA Supervisor: Piotr Żebrowski, Matthias Wildemeersch, Advanced Systems Analysis

Introduction. Modern agriculture requires careful management of soil moisture during the growing season. A common approach to removing excess water from cropland is artificial drainage which may take the form of surface ditches or subsurface piping. In regions with wetlands isolated from a stream network, artificial drainage necessary leads to the accumulation of water in wetland basins to counterbalance its removal elsewhere. Furthermore, the change in exposed water surface area may lead to differing rates of evapotranspiration in a natural landscape relative to a drained one. We developed two distinct types of novel hydrological models to study this phenomenon in prairie wetlands in central North America with separate emphases on 1) statistical estimation of model parameters from noisy data and 2) realistic representation of ponded water merging and splitting under hydroclimatic variation.

Methodology. In a given landscape, the drainage channels connecting disparate wetland basins can be viewed as a network with edges connecting uphill locations to potential downhill receiving basins. We pose the management of a drainage network as an integer-valued graph optimization problem in which an optimal solution maximizes the amount of land which is free of water during the growing season but also maximizes the interannual variation in ponded water surface as this variation is a key control on land value for regional wildlife. Using our newly-developed model, we conducted simulations to assess the optimality of different drainage networks.



Results. While connecting all basins with surface channels leads to collection of water in a single location, it is not optimal with regard the value of the land either for agriculture or wildlife. Furthermore, pairwise drainage connections without a larger network structure appear to have little impact. The drainage graph leading to the most substantial reduction in inundated area appears to take the form of a chain network consisting of a sequence of connected depressions with little to no branching.

Conclusions. Our results indicate that there is an optimal strategy for water management which does not entail drainage of every landscape depression into a single water body. These simulations reveal that some small ponds and wetlands are very efficient at utilizing evapotranspiration and should be kept separate from a larger artificial drainage network. In future work, we intend to solve a stochastic optimization problem to more fully explore the range of possible and optimal solutions for this problem. Our findings have important ramifications for understanding the long-term risks of inundation and flooding due to manipulation of surface hydrology in the American prairies and other postglacial landscapes with weak topographic gradients.

Global iron & steel supply chain networks: Assessing system robustness between 1995-2015 in a physical input-output framework

Hanspeter Wieland, Vienna University of Economics and Business, Austria
Email: hanspeter.wieland@wu.ac.at
IIASA Supervisors: Brian Fath (ASA) and Klaus Hubacek (WAT)

Introduction. Iron is a strategically important resource for industrialized and industrializing economies. Trade plays a crucial role in securing the supply of those countries in which ores are not extracted. In 2015, only five countries (BRIC + Australia) accounted for 85% of global iron ore extraction. The intensifying spatial disconnect (between extractors-processors-users), unprecedented growth rates of global extraction (ca. 9% p.a.) and the threefold increase of trade volumes since 1995, signify a highly dynamic global iron-steel (I-S) supply chain network that is going through profound structural change. The overarching goal of my project is to elucidate vulnerability hotspots within global I-S supply chains by assessing network structure and robustness of the system.

Methodology. This work is based on a global physical input-output table (PIOT) for I-S, which is an integrated dataset covering supply and use of global I-S flows, aggregated into 21 commodities for 34 countries and a "rest of the world" region. I use network analysis to identify key actors and assess different network properties and their development over time (1995–2015) for various layers of the I-S supply chain (primary iron, semi-finished/finished steel, scrap and steel in final consumer products). Applying information-based ecological network analysis (IB-ENA), I assess the degree of order and robustness, i.e., the balance between efficiency and diversity in the system of the different layers and the overall network.

Results. The density of trade networks, which is the portion of the potential bilateral trade relations that are actually realized, increases with the degree of processing. Primary iron, the initial layer/stage of the supply chain, is the least dense (19%) whereas steel in final consumer products is the densest (92%) trade network. Changes over time are most profound for scrap (from 22 to 31%) and final products (76 to 92%). The IB-ENA results reveal little redundancy and high levels of specialization in the system. In 2015, the highest degree of order is found for semi-finished steel (0.92), scrap (0.84) and finished steel (0.56). Trade networks of primary iron and final products display the greatest balance between efficiency and diversity and consequently moderate degrees of order (0.48 and 0.56). Additionally, these two layers have diversified while the others have specialized over the past two decades.

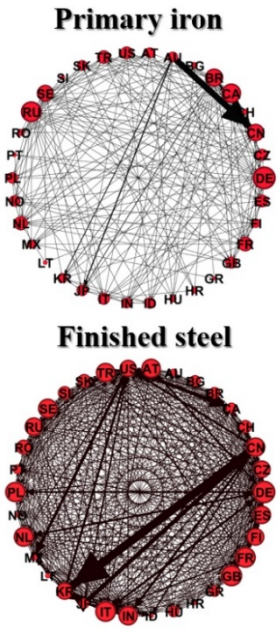


Figure 2: Trade networks of primary iron and finished steel in 2015.

Conclusions. The robustness of global I-S network is relatively high. In line with other IB-ENA studies analyzing trade networks (Kharrazi et al. 2017), we find the unprecedented growth rates in trade and ore extraction to be facilitated by a high degree of order in the system. The results indicate distinct network patterns for the various layers of the supply chains. Diversification in trade of primary iron is complemented by growing specialization in the trade network of finished steel, which seems to be related to the growing dominance of China and the diminishing importance of Japan within these networks. Trade networks of scrap and semi-finished steel feature the lowest levels of robustness. Countries playing an important role within these networks, such as Turkey and a few European countries seem to be the most vulnerable actors in the network.

Kharrazi A, Rovenskaya E, Fath BD (2017) Network structure impacts global commodity trade growth and resilience. PLoS ONE 12(2): e0171184. https://doi.org/10.1371/journal.pone.0171184

Energy
(ENE)

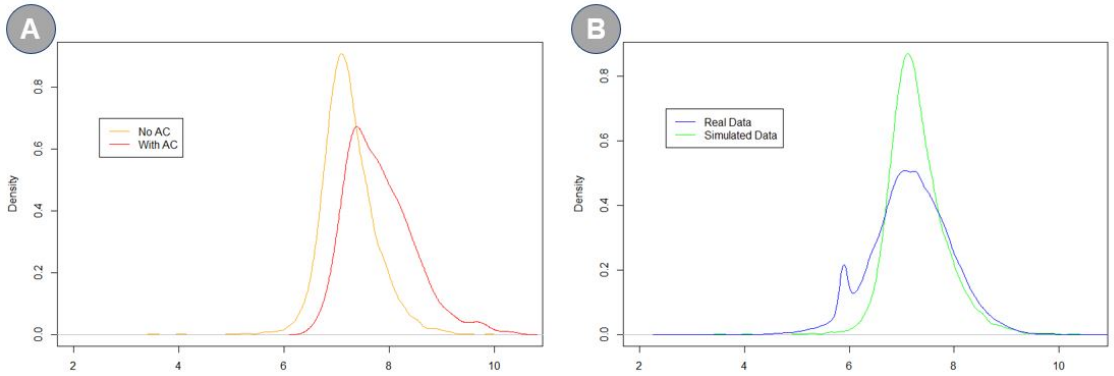
Modelling social heterogeneity: How does a better representation of income inequality affect energy choices in Brazil?

Talita Cruz, COPPE/UFRJ, Brazil
Email: talitaborges@ppe.ufrj.br
IIASA Supervisor: Shonali Pachauri (ENE) and Miguel Poblete Cazenave (ENE)

Introduction. Two urgent global challenges that we face today are climate change and economic inequality. However, current models used to explore climate mitigation policies and actions have a limited ability to represent the poor and vulnerable. There is, therefore, a need for energy systems and integrated assessment models (IAM) to incorporate socio-economic heterogeneity and behavioural realism, for a more realistic representation of end users' energy choices and demand patterns. This project contributes to this end by developing a residential energy model for Brazil that can capture heterogeneity in consumer behaviour across the entire income distribution and assess key drivers of varying energy end uses in the home.

Methodology. Micro-datasets from Brazil's nationally representative household survey were analysed to understand existing energy patterns. The data was used to calibrate a structural model of household energy choice. The model builds on the existing MESSAGE-Access model but extends it for additional energy end-uses and applies it to Brazil for the first time. The model creates a simulated dataset using a set of auxiliary logistical regressions. The tool then allows for estimating energy demands at an individual household level by minimizing the difference between the simulated and real data.

Results. Analysing existing energy patterns for the residential sector in Brazil, we confirm the importance of accounting for socio-economic heterogeneity in end users' energy choices. As shown in Fig. A, we can reproduce the distribution of households with and without air conditioning for space cooling. In Fig. B, we find that the model provides a close approximation to the observed electricity use pattern for all end-uses compared to the survey data.



Conclusions. The model developed improves our understanding of the key drivers of consumers' energy choices in Brazil, allowing for an examination of the link between income, residential energy demand and energy prices. This allow us to draw more reliable implications for future energy demand and potential mitigation options. This development is a first step to better represent consumer heterogeneity in an IAM. The next step is to create a soft link of this model with an IAM, so that macro-economic feedbacks from a larger energy system can be captured.

Energy-food-health nexus of grain supply losses in India

Matthew Gibson, Imperial College London, UK
Email: matthew.gibson14@imperial.ac.uk
IIASA Supervisor: Narasimha Rao (ENE) and Arnulf Grübler (TNT)

Introduction. Food loss and waste is a universal problem with global consequences. This study will take a multi-scale systems perspective of grain storage losses in India. It quantifies the foregone nutrition across major grains (rice, wheat, maize, bajra, sorghum), the potential to improve nutritional deficiency, and the useful energy needs to reduce these losses. Future production growth and possible grain share diversification are explored and policy implications discussed.

Methodology. Quantitative storage loss rates for major Indian grains across 14 agro-climatic zones were mapped with district level crop production data to give the tonnage of lost grains in each district. Nutritional profiles (calories, protein, iron, zinc, vitamin A) for each grain were combined with these loss totals to generate annual quantities of foregone nutrition. Population nutrient deficiency data were used from previous work (Rao et al. 2018) to calculate the proportional improvement in nutrition (by aggregate, state, and grain level) by eliminating these losses. The energy angle is explored by constructing a simplified physical model of the initial drying and cooling requirements and ongoing maintenance of conditions. The energy model is parameterised and bounded with biophysical grain properties, agricultural storage practices, and industry literature. Uncertainty and sensitivity are explored with Monte Carlo simulation.

Results. Losses in India's food grain during drying and storage amount to 1.8 million tonnes per year. Preliminary results show that eliminating these losses can provide a nutritional 'dividend', reducing the national protein and iron deficit by around 5%. This dividend shows high spatial and urban/rural heterogeneity. Useful energy to reduce grain losses displays uncertainty but is in the region of 18 TWh per year**.** For reference, annual electricity consumption in agriculture is around 173 TWh. Useful energy intensity also shows uncertainty but differs per grain, with maize (0.11 kWh/kg) and rice (0.10 kWh/kg) the highest, followed by sorghum (0.09 kWh/kg), bajra (0.08 kWh/kg), and wheat (0.07 kWh/kg). This is around 5-20% of the input energy intensity in producing these grains. Diversifying some rice production to bajra could reduce losses and the useful energy requirements.

Conclusions. This study gives a systems perspective of the potential to address a portion of India’s nutrition deficit by reducing losses in grain drying and storage, and characterises the useful energy needed to do so. It illustrates interactions between, and progress toward, several Sustainable Development Goals (SDGs); hunger (SDG2), health (SDG3), energy (SDG7), and production and consumption (SDG12). Results offer policy relevance, adding to evidence supporting the diversification of grain consumption from rice to coarse grains such as bajra. Key uncertainties concern the heterogeneity in loss rates and specific harvest and storage parameters for different grains in different climates. Future work could explore this spatial variation as well as expand the analysis to other food groups and geographic regions (e.g. Sub-Saharan Africa).

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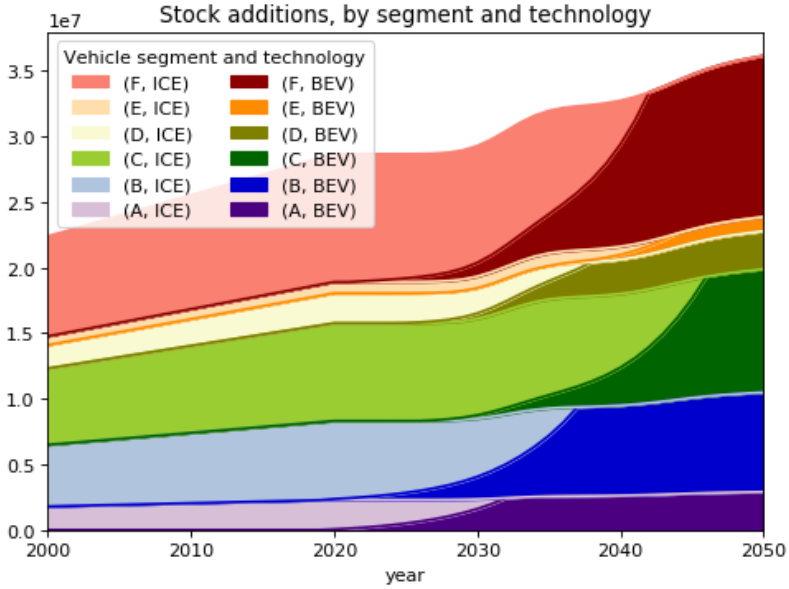
Prescribing policy for sustainable transport electrification pathways

Christine Roxanne Hung, Norwegian University of Science and Technology (NTNU), Norway
Email: christine.hung@ntnu.no
IIASA Supervisors: Paul Kishimoto (ENE) and Arnulf Grübler (TNT)

Introduction. The transport sector, particularly road transport from passenger cars, contributes a significant portion of global anthropogenic climate change emissions. Battery electric vehicles (BEVs) replacing conventional fossil-fuelled vehicles (ICEVs) are widely endorsed as a climate mitigation measure. However, previous lifecycle assessment (LCA) studies have shown that the mitigation effects of BEVs are highly sensitive to the electricity mix used to charge BEVs in the use phase. In some cases, due to BEVs having higher lifecycle climate change emissions than their ICEV counterparts (Ellingsen et al, 2016), electrification might result in an increase in greenhouse gas emissions. Transport electrification policies must therefore be carefully designed to ensure that the resulting transition reduces climate emissions as much as possible.

Methodology. To evaluate the climate effects of transport electrification pathways, we combine emissions factors for the entire vehicle lifecycle with a dynamic stock model of the European passenger car fleet. The model differentiates between ICEs and BEVs, as well as six vehicle size segments, and different maximum ranges for each BEV segment. The model takes fleet statistics and LCA factors with projections for future transport demand, the carbon intensity of the electricity mix and decreasing emissions and energy intensities of vehicle production, use, and disposal as input. The model outputs the fleet composition that minimizes total carbon emissions from the passenger vehicle fleet in the 2020 – 2050 period under different scenarios.

Results. Under a scenario where local governments invest heavily in charging infrastructure to alleviate consumer range anxiety, manufacturers may equip their small- and medium-sized BEVs with smaller batteries because charging is more accessible. These vehicles, with correspondingly shorter ranges than current BEV models, would decrease the production emissions, to which the battery contributes significantly. In contrast, the current trend has been increasing range of BEVs within segments. Compared to the current BEV ranges on the market, the infrastructure-accessible scenario introduces mid-range (B- and C-segment) BEVs more quickly and has lower overall emissions over the studied period.



Conclusions. Minimizing the emissions related to the electrification of the passenger vehicle fleet in Europe is highly dependent on the market evolution of BEVs. The current trend of increasing BEV range delays the emissions-optimal electrification of the fleet to take advantage of production efficiencies and decarbonization of the electricity sector.

References

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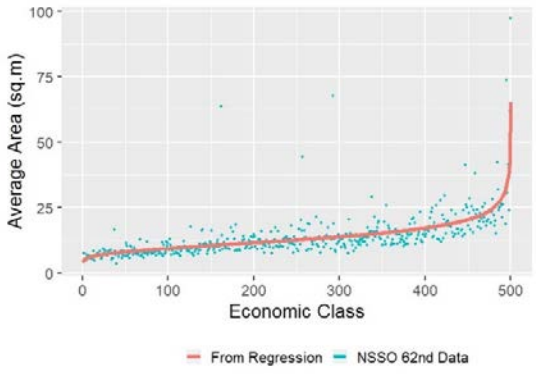
Indian residential buildings: Future growth and energy impacts

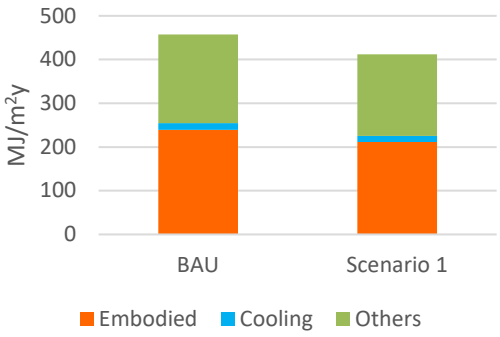
Aishwarya Iyer, Yale University, USA
Email: aishwarya.iyer@yale.edu
IIASA Supervisors: Alessio Mastrucci (ENE) and Narasimha Rao (ENE)

Introduction. India, a global hotspot for urban development, is expected to be the most populated country by 2030, and the floor space is also expected to double by then. The energy demand and environmental impacts from this massive uptake of construction are expected to be significant. This project aimed at identifying the important variables impacting residential area and structure types, calculating energy impacts from different types of buildings that could be built, and projection of possible future compositions of the Indian urban residential buildings. The identification of important variables and energy analysis of 2 archetypes of buildings was completed over the summer.

Methodology. Two datasets from 2005-06 and 2012-13 that catalogued residential area with some other socioeconomic variables were analyzed. Statistical analysis using regression and logit models, revealed which variables were most influential towards residential housing characteristics. Different archetypes of buildings need different materials and amounts of energy for construction and usage. Two such archetypes were studied and compared based on direct and indirect energy consumption.

Results. The statistically significant variables impacting residential area and the structure type of the construction (permanent vs. non-permanent) were found to be – economic (indicated by monthly per capita expenses (MPCE) and total value of asset ownership), number of people in the house, the type of city in which the house is located, and age of the head of the household. Two representative building archetypes with different material mixes were studied and comparing the direct and indirect energy consumption shows that adopting new methods of construction can reduce 10% or more of total lifetime energy consumption.





Conclusions. This study shows that apart from economic status, location and demographic variables also impact the size and type of house. These are variables using which a better and more accurate prediction of residential housing composition in the future can be made. Energy comparisons show that the direct and indirect energy consumption of different archetypes is instrumental in understanding future impacts of residential building growth. Future steps will use relationships discovered between variables here to project more detailed future scenarios. Also, more archetypes will be explored for future building scenarios.

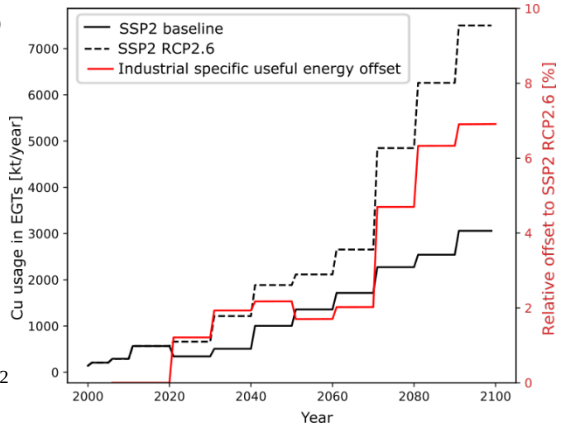
Understanding the impacts of biophysical constraints on IAM results – linking a bottom-up demand-side model and the MESSAGE model: the case of copper

Stefanie Klose, University of Freiburg, Germany
Email: stefanie.klose@indecol.uni-freiburg.de
IIASA Supervisors: Volker Krey (ENE) and Jihoon Min (ENE)

Introduction. The MESSAGE Integrated Assessment Model (IAM) is a powerful tool to provide relevant analysis on cost-efficient climate mitigation pathways. These scenarios contain considerable detail for energy conversion technologies and greenhouse gas emissions. However, although most of the green development pathways are very technology- and thus material-intensive, material cycles are not explicitly modelled in MESSAGE. Thus, the environmental impacts of strongly increasing material demands in mitigation scenarios is not considered until now. One aim of this study is to introduce material cycles into MESSAGE and thus, make the resulting policy advice more robust. Furthermore, the sustainable transition pathway results from MESSAGE shall be used within the Open DYnamic Material flow model framework of the Resource Efficiency and Climate Change (ODYM-RECC) assessment. This integration will enable a more holistic assessment of the potential contribution of resource efficiency to climate change mitigation.

Methodology. Since green energy technologies are very copper (Cu) intensive, we analysed the impact of the copper cycle from copper embodied in electricity generation technologies (EGTs) on MESSAGE model results and on prospective copper demand in different scenarios. The ODYM-RECC-MESSAGE linkage (OMli) creates a common model scope between these two models. The ODYM-RECC sectoral and regional scope was extended and the energy usage from mining, waste management and manufacturing of copper in EGTs was assessed for the SSP1 and SSP2 baseline and RCP2.6 scenarios. The offset resulting for the RCP2.6 scenarios was evaluated for energy use and CO_2 emissions. (GitHub repository: https://github.com/SteffiKlose/OMli)

Results. In the year 2100 the copper demand for the SSP1 scenario amounts to 4050kt in the baseline and 6900kt in the RCP2.6 scenario. For the SSP2 scenario the copper demand sums up to 3060kt (baseline) and 7500kt (RCP2.6). Solar photovoltaic power plants are in all scenarios the technology dominating copper usage. The difference in energy requirements (with only considering electricity by now), associated with the copper demand and processing between baseline and RCP2.6 scenarios amounts to 2EJ for SSP1 and 4EJ for SSP2. For SSP2 RCP2.6 this is an addition of 7% to industrial specific useful energy and 0.8% of total CO_2 emissions in the year 2100.



Conclusions. In today's annual global copper demand of 24000kt, EGTs contribute to not more than 1%. The results of this study clearly show that technological development pathways and climate change mitigation policies have a strong impact on prospective copper demand and that the share of EGTs might increase. Even though the offset to total CO_2 emissions assessed from this first case study is not considerable, the results still show that energy demand from copper in EGTs visibly impacts industrial specific useful energy in MESSAGE. Therefore, it is worth to further explore the impact of material cycles on MESSAGE results and expand the scope of OMli.

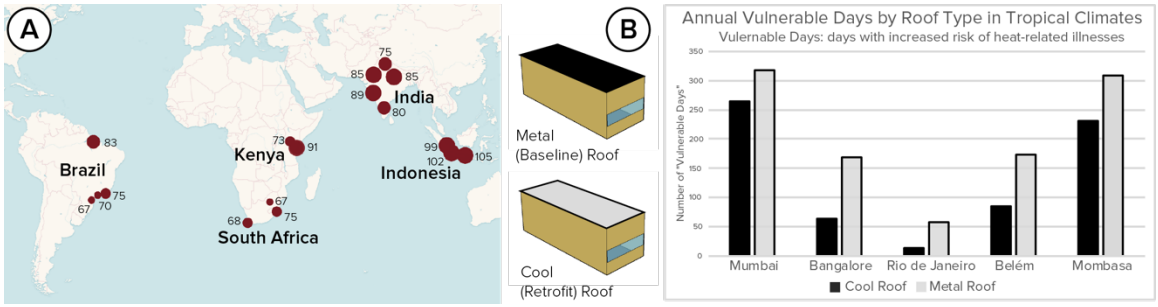
Characterization of urban informal settlements in the Global South: Assessing key design parameters to improve thermal comfort and building energy consumption

Alex Nutkiewicz, Stanford University, USA
Email: alexer@stanford.edu
IIASA Supervisors: Alessio Mastrucci (ENE) and Narasimha Rao (ENE)

Introduction. Cities are critically important to meeting our sustainable energy goals. Specifically, urban informal settlements of the Global South, alongside ongoing improvement and redevelopment projects, represent an opportunity to redesign dwellings to improve living conditions while placing us on a trajectory towards more energy efficient cities. However, we lack understanding for how decisions made by policymakers today will impact human factors like thermal comfort and energy use. This work aims to develop a generalizable energy modelling framework to represent urban informal settlements globally. As a result, we show how localized, in-situ retrofits of existing slums can eliminate the demand for active cooling and subsequent energy burden for informal settlements.

Methodology. We developed an urban energy modelling framework capable of modelling the urban built environment of informal settlements across the world. We first collected data to describe informal settlements using remote observations. This data describing various building materials, urban features, and operational factors became the parameters for a physics-based energy simulation which calculates the indoor temperature and humidity of a building for each day out of the year. Our models output the daily Heat Index for each simulation in order for us to assess the vulnerability of slum dwellers to heat stress under varying combinations of building parameters.

Results. We modelled and simulated 152,004 design scenarios across 5 countries, 17 cities, and 4 existing (M1, M2) and proposed high-rise (B1, B2) building morphologies. Our results indicate thermal vulnerability, dictated by Heat Index, is highest in urban informal settlements located in "tropical" climate zones (Fig. A). Additionally, these locations are also most sensitive to changes in building envelope constructions (roofs, walls, floors) – meaning that small, incremental improvements will likely result in substantial improvements to the indoor thermal comfort for occupants. A small in-situ retrofit of updating existing corrugated metal roofs with a low-cost cool roof paint (Fig. B) resulted in a 6% reduction in monthly Heat Index in tropical locations and demonstrates how small incremental retrofits can reduce the demand for energy-intensive active cooling solutions for future climate scenarios.



Conclusions. The decisions decided today about slum upgrading and redevelopment will undoubtedly shape the thermal comfort and subsequent urban energy demand for decades. By establishing a generalizable energy modelling framework to characterize informal settlements across cities and nations, our work has significant implications for how we can inform slum incremental upgrading and redevelopment to enhance occupant living conditions and set our cities on a pathway to a sustainable energy future.

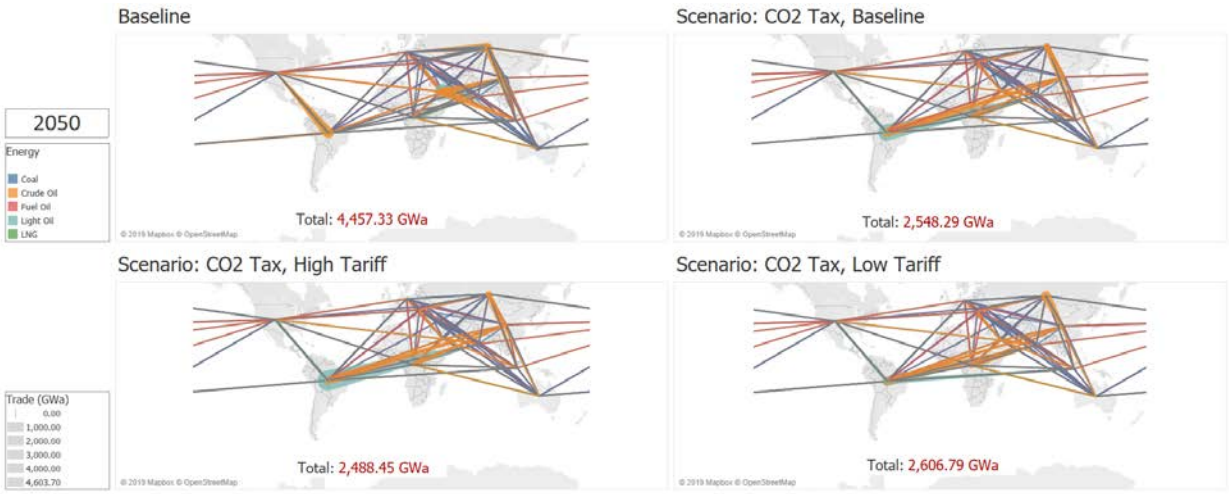
A representation of transportation and trade networks in global energy models

Jun Ukita Shepard, Duke University, USA
Email: jun.shepard@duke.edu
IIASA Supervisors: Bas van Ruijven (ENE) and Behnam Zakeri (ENE)

Introduction. Regional energy systems are inextricably tied to international trade and shipping networks. However, current energy models generally do not address the dynamics of these networks. These dynamics are particularly important in the context of technological transitions; shifts in regional demand will break existing trade linkages while forming new ones. This project explores the effects of trade policies on long-term energy trade networks. These trade networks do not only impact energy security but also have consequences for meeting emissions targets.

Methodology. The MESSAGE energy model represents the global energy economy using 14 representative regions. It assumes a "global pool" trade schema, in which each region exports into/imports from a global resource pool. We transition MESSAGE to a bilateral schema by specifying bilateral trade flows for five energy commodities. We also introduce shipping networks, thereby exploring the effects of trade trajectories on investment into new shipping technologies specified by cargo and fuel. We analyse 12 scenarios, exploring the effects of tariffs, sanctions, technological advancements in shipping, and emissions taxes on energy trade networks from 2020-2110. Each scenario is represented in importer or exporter variable costs.

Results. Results suggest that sustained tariff policies may change the composition of trade flows. For instance, under a low-tariff scenario light oil exports from the Middle East to Southern Asia are substituted by crude oil exports. Results also suggest that short-term sanctions between regions can have a lasting effect on energy trade networks and the overall cost of the global energy system. Most notably, sanctions between North America and the Middle East can increase the global system cost by 24% from the baseline. Trade policies have heterogenous impacts on regional emissions, though increased trade friction generally reduces regional emissions. The effects of trade policies on global emissions are marginal. Emissions taxes significantly alter the trajectory of global energy trade networks. Results suggest that not only do the structures of the networks change, but the magnitude of fuel trade can also decrease by 50% by 2050.



Conclusions. The results of this project suggest that trade policies, such as sanctions and tariffs, can shape long-term energy trade networks. They also underscore the indirect effect of trade policies on emissions; increased trade frictions can lead to regional reductions in emissions but have little impact on global trajectories. Emissions tax scenarios can have significant implications for future trade networks. Trade diversity, an index for measuring energy security, appears to generally decrease across energy commodities over time.

Ecosystems Services and Management (ESM)

Do more trees mean more carbon? How land use disturbs the tree cover–carbon stock correlation in the tropics

Manan Bhan, Universität für Bodenkultur (BOKU), Austria
Email: manan.bhan@boku.ac.at
IIASA Supervisors: Steffen Fritz (ESM) and Inian Moorthy (ESM)

Introduction. Tree cover and carbon stocks in terrestrial ecosystems are key ecosystem attributes, and their characterization is central towards evolving resource management and climate mitigation strategies. Satellite-image based assessments have attempted to map these attributes to complement field-based efforts, but these assessments often disagree on the magnitude and location of ecosystem change. We use existing datasets of stocks and changes over contemporary timescales (2000-2014) to highlight the role of anthropogenic disturbance, thereby highlighting the role of land use in natural ecosystems in disturbing the Tree Cover – Carbon Stock continuum.

Methodology. We fused existing datasets of Tree Cover (TC) and Carbon Stocks (CS) to develop 'best-guess' estimates[1] and run spatial correlations to analyse their character in time and space. Using land use proxies[2] as moderating variables, we highlighted the role of land use in the diverging TC-CS relationship in a regression model. Deviation (i.e. distance) from the potential TC-CS relationship was attributed to various land uses. Consequently, we developed a TC-CS change divergence map (spatial resolution of 5 arc minutes, approx. 10kms at the Equator), and mapped drivers of change[3] to each individual pixel to isolate sub-continental land use drivers of ecosystem change.

Results. Local neighbourhood spatial correlations on our 'best-guess' TC and CS maps showed a lower correlation in wilderness[4] areas, highlighting spatial discontinuities and anthropogenic footprints even in so-called 'wild' lands. We found a significant land use footprint through the use of proxies in our regression model in more than half of our study area, dominated by Tropical Rainforests, Moist Deciduous Forests and Shrublands. Current correlation values remain far from potential ones, highlighting the role of land use in disturbing the TC-CS continuum. Our change divergence map shows the lack of agreement of ecosystem change among existing datasets. The dominant drivers of the divergences are found to be shifting cultivation and commodity-driven deforestation, complementing previous regional and sub-continental studies of land use change.

Conclusions. This study sheds light on an under-studied aspect of ecosystem change: the role of land use. We find divergences from the intuitive relationship of TC and CS among spatial datasets in the tropics and find evidence that these disagreements can be attributed to the role of land use and land management. We find evidence of anthropogenic disturbance even in seemingly 'wild' landscapes. Disagreements among change datasets persist and are driven by sub-continental level drivers. The study assumed increased importance in light of resource management and modelling initiatives, as well as the stock-taking activities planned under the Paris Agreement.

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Assessing synergies and trade-offs between biodiversity conservation and carbon stock under climate change in South Korea

Yuyoung Choi, Korea University, South Korea
Email: cuteyu0@korea.ac.kr
IIASA Supervisors: Anatoly Shvidenko (ESM) and Dmitry Schepaschenko (ESM) and Florian Kraxner (ESM)

Introduction. Forests play an important role in responding to climate change, and there is a diverse range of reasonable feedbacks of forest management such as maintaining biodiversity, increasing carbon sequestration and wood production etc. Forest management to achieve each goal may have synergic effects but there are also many conflicts among ecosystem services and corresponding measures. The study aims to evaluate the national afforestation plans by considering the impact on biodiversity and carbon stocks in South Korea.

Methodology. We established spatial scenarios of afforestation based on the national forest management plans with 5,800ha of expansion target by 2022. Afforestable area were identified based on land cover, climate, altitude and soil depth. For selected afforestable regions, Generalized Dissimilarity Modelling (GDM) and Global Forest Model (G4M) were used to derive the scenarios that maximize biodiversity (Biodiversity focused Afforestation scenario: BfA) and carbon storage (Carbon focused Afforestation scenario: CfA) respectively. The derived scenarios were then applied to each model. The scenario maximizing carbon stock is applied to the model focusing on biodiversity change and vice versa, which allowed the result to be analyzed quantitatively.

Results. The result of the models integrating each scenario presented the optimal afforestation area for biodiversity maximization and carbon maximization. To secure biodiversity conservation, the afforestation should be near the high-altitude of the mountain ranges, while to secure carbon stock, it should be in low-altitude adjacent to cities or croplands. The estimated proportion of plant species persistence increased from 92.97% in the current state to 93.118% in BfA scenario. Under the CfA scenario, the biodiversity persistence was also increased to 93.105%, which is slightly lower than the result of BfA. On the other hand, we identified a maximum of 1,275,241m^3/ha stem volume can be increased under the CfA scenario, whereas under the BfA scenario, 552,700m^3/ha obtained, which is about 43% of the maximum volume.

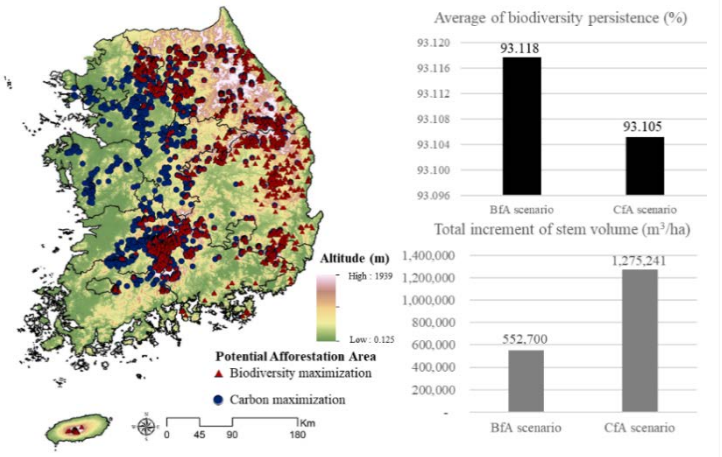

***Figure**. Optimal afforestation location of each scenario (left); Changes in biodiversity persistence and stem volume for each scenario (right)*

Conclusions. In this study, we identified the optimal afforestation area and quantitatively assessed the effect of afforestation. Although the expansion of forest has a positive effect on both biodiversity and carbon storage, maximization condition of each objective indicates a few losses of the other objectives. Our results highlight the need to jointly determine the spatial distribution of afforestation for simultaneously supporting biodiversity conservation and mitigation of climate change.

Renewable energy directive (RED II)'s contribution to employment and GDP growth

Bertram F. de Boer, Leiden University, The Netherlands
Email: b.f.de.boer@cml.leidenuniv.nl
IIASA Supervisors: Michael Obersteiner (ESM) and Hugo Valin (ESM)

Introduction. The European Union (EU) needs to drastically change its energy system to meet its climate goals. To enact this change, the EU follows a three-pronged approach, namely reducing greenhouse gas emissions, increasing energy efficiency and increasing the share of renewable fuels. This approach promises to create new economic opportunities in the EU. It is unclear however, what the contributions of each approach are to this promise. This study focuses on the latter approach, i.e. increasing the share of renewable fuels through the Renewable Energy Directive II (RED II), to better understand its impact on employment and GDP.

Methodology. We employ a scenario aiming to increase the share of renewable energy to 32% and energy efficiency by 32.5%, which we transform into feedstocks shifts for solid and biofuel production. We implement these changes in a computational general equilibrium model, namely EXIOMOD, obtaining relative impact on value added, employment, and the production and imports of biomass. We implement the latter in a partial general equilibrium model, namely GLOBIOM, obtaining changes in carbon, material, water, and land footprints, and production in NUTS-2 classification. These detailed production results are used to disaggregate the output of EXIOMOD on shifts in value added and employment to NUTS-2. Finally, we contrast these findings against a baseline which does not include increases in the share of renewable energy and energy efficiency.

Results. Between 2020 and 2030, we find an increase in EU28 feedstock production for solid biofuel of 34%. The EU forest sector currently employs 0.5 million people, and half of its output goes to energy use. Therefore, we expect to find a significant positive impact in value added and employment, even if this growth will have indirect impact on other sectors. In the case of liquid biofuels, the EU policy increases from 10% to 14% the share of renewable energy in transport, with a 3.5% requirement from advanced biofuels and biogas and a phase out of feedstocks with high indirect land use change risk, namely palm oil. In spite of the limited expansion of these fuels, we expect some relatively higher impacts on production of liquid biofuels feedstocks in the EU due to the phase out of palm oil and uptake of second generation feedstocks.

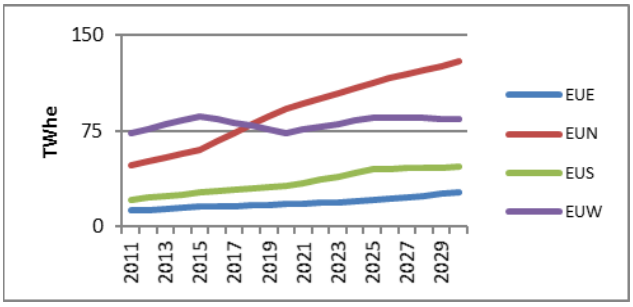

Figure 3 - Gross Electricity generation by biomass-waste (PWhe) according to the scenario aiming at a share of 32% renewable energy for four EU28 regions, namely Northern Europe (EUN), Southern Europe (EUS), Western Europe (EUW), and Eastern Europe (EUE).

Conclusions. The aim of this study is to assess shifts in value added, employment, and environmental footprints due to RED II. Our preliminary analysis suggests a strong increase in feedstock production for solid biofuels, and a large geographical shifts for liquid biofuels from imported to domestically produced feedstocks. Future actions include confirming the results above by further integration of the modelling tools and disaggregating the associated impacts to subnational level.

Accounting of scope 3 emissions (LCA) into the *BeWhere* model

Carlos Andrés García-Velásquez, Aachen-Maastricht Institute for Biobased Materials, Maastricht University, The Netherlands
Email: c.garciavelasquez@maastrichtuniversity.nl
IIASA Supervisor: Sylvain Leduc (ESM)

Introduction. The worldwide consumption of plastics has increased in the las few years due to the high requirements for packaging, building and automotive materials. The global economy produced 407 Mt of plastics in 2015, with carbon emissions up to 1.7 Gt of CO2-equivalent due to the high demand and production of fossil-based plastics 1. Additionally, the annual plastics production is expected to grow to 1,606 Mt by 2050 1. Therefore, we need to find a solution to produce plastics in order to mitigate the environmental impact and economic dependency from fossil resources. In this sense, the use of biomass to produce plastics has arose as a promising alternative solution that can wholly or partly substitute fossil-based plastics. Nevertheless, it is still unclear if the biobased plastics can be produced in an economically viable and environmentally friendly way in comparison with fossil-based materials when direct and indirect emissions are considered in the whole assessment.

Methodology. The spatial-explicit optimization model (BeWhere) was used to correlate environmental and economic criteria in order to provide a framework that considers the direct and indirect emissions (Scope 3 emissions 2) to support decision-makers on the design of the value chains. The production of 30%-biobased PET (polyethylene terephthalate) was selected as study case using three feedstock sources: maize, sugar beet and wheat. The techno-economic assessment was used to estimate the production costs of the case study, whereas the Life Cycle Assessment (LCA) methodology was used to estimate the indirect emissions.

Results. The emissions related to the LCA of the PET production account up to 91.4% (wheat case) of the total emissions, whereas the remaining 8.6% accounts to the transportation. The results change depending on the feedstock, the configuration of the supply chain network (transportation network) or the need of fossil PET to supply the current demand. Additionally, the economic contribution of the carbon missions in the production costs can account for up to 90% depending on the economic value. Carbon tax is used as a monetization value of these emissions.

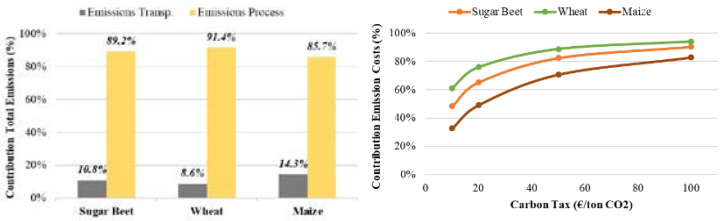

Figure 1. Contribution of the transportation and life cycle assessment emissions throughout the whole supply chain network.

Conclusions. Scope 3 emissions should be considered for the environmental assessment of biobased materials, especially when they account more than 85% of the total greenhouse gas emissions. The use of a carbon tax on those emissions is highly important to provide a monetization value that could influence the economic performance of the process. The integrated use of economic and environmental criteria will help to properly analyse biomass supply chain networks and serves as a powerful decision-making support tool.

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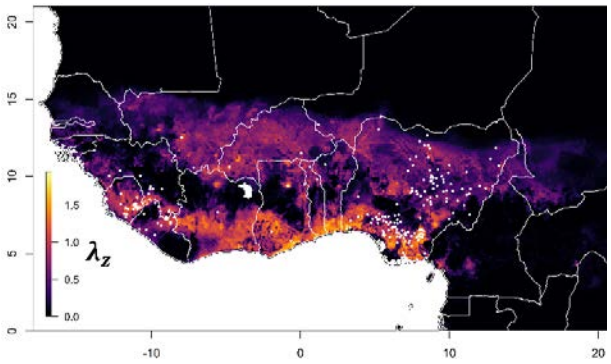
Interacting effects of land use, climate and socioeconomic change on Lassa fever risk and vulnerability in West Africa

Rory Gibb, Centre for Biodiversity and Environment Research, University College London, UK
Email: rory.gibb.14@ucl.ac.uk
IIASA Supervisors: Piero Visconti (ESM) and Tamás Krisztin (ESM)

Introduction. Changing agricultural systems and associated biodiversity changes drive outbreaks of many zoonotic (animal-borne) diseases, emphasising the need to identify synergies and trade-offs at the nexus of food security, biodiversity and infectious disease. Lassa fever (LF) is an endemic rodent-borne zoonosis linked to rural livelihoods and climatic factors in West Africa, a region projected to experience extensive cropland expansion and climate impacts in the coming decades [1]. Understanding how future agricultural pathways are likely to affect LF burden is critical for targeting disease surveillance and control towards vulnerable populations.

Methodology. We develop a spatially-explicit, process-based model of zoonotic LF transmission at the human-rodent interface. Relative density of reservoir host *Mastomys natalensis* is determined by land-use-land-cover (LULC) and species climatic envelope, parameterised from statistical models. Per grid-cell human LF infection risk (Poisson λ_z) is modelled as a logarithmic function of human-reservoir contact density. We project the model using socio-environmental data for present day, and for 2050-2070 SSP-RCP scenarios using downscaled climate, LULC (from GLOBIOM) and population projections. We propagate land use/climate uncertainty into predictions by Monte-Carlo sampling across future environment ensembles (100 LULC iterations, 4 GCMs, 100 envelope models per-scenario).



Predicted and observed Lassa fever distribution. Colour shows modelled annual cases per grid-cell (Poisson λ_z) and white points are locations of LF outbreaks (1990-2019).

Results. The risk model accurately reproduces the current distribution of LF in West Africa (Figure). By 2050, total LF cases are predicted to increase by 33-53% (SSP1), 55-73% (SSP2) and 65-94% (SSP3). Controlling for human population increase, land and climate change-driven increases in rodent density together account for a 20%-50% overall increase in cases by 2050, with largest environmental effects in SSP3. These effects are notably strongest in central and northern Nigeria, where LF is currently rapidly emerging, resulting from synergistic effects of cropland expansion and climate change. Conversely, under lower-impact scenarios environmental risk reductions are expected in countries (e.g. Liberia) predicted to experience lower natural vegetation losses. Environmental uncertainty is highest at the northern edges of LF risk distribution.

Conclusions. Future agricultural land expansion has potential to interact with climate change to increase human-reservoir contact and LF risk, including in countries (e.g. Nigeria, Guinea) that are currently hyperendemic for the disease. Improvements in human and rodent surveillance, and LF diagnostic capacities, are urgently needed in economically-vulnerable areas of rapidly increasing risk, especially northern Nigeria.

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Economic valuation of adaptation scenarios to mitigate the urban heat island effect in small and medium-sized cities

Daniel Johnson, ESCP Europe Berlin, Germany
Email: djohnson@escpeurope.eu
IIASA Supervisors: Linda See (ESM) and Tamás Krisztin (ESM)

Introduction. With high rates of urbanization and elevated temperatures due to climate change, cities are becoming increasingly stressed by the urban heat island (UHI) effect. This effect has been shown to have negative impacts on human health in urban areas. Adaptation measures such as green roofs, trees, low vegetation and unsealing (referred to collectively as 'green measures') provide numerous additional benefits compared to the albedo-increasing measures of light-colored streets, walls and roofs (or 'white measures'). We estimate the economic value of a combination of such green and albedo-increasing measures in three small- to medium-sized cities in Austria (Mödling, Klagenfurt and Salzburg), as understudied cases of the UHI, and compare the valuation against typical costs in a social cost-benefit analysis.

Methodology. In the present work, monetarily valued benefits of adaptation included reduced heat-related mortality, morbidity, productivity, heating and cooling loads, stormwater runoff, air pollution, and carbon dioxide as well as an increased provision of habitats, property value and longevities of buildings. The temperature-mortality relationship was modeled with a time series analysis (2003-2017) of daily maximum temperature and daily all-cause mortality from the 3 cities in a distributed lag nonlinear model (DLNM). Urban climate modelling of the cities was carried out in the ADAPT-UHI project to estimate the UHI and model the average change in the number of hot days (Tmax > 30°C) as raster grids given a combination of measures. We value the reduction of hot days as a reduction in mortality risk given the number of residents in each raster cell and the reduction of hot days in each raster cell summed over each city.

Results. The DLNM indicated increasing relative risk of mortality beginning at the minimum mortality of Tmax > 25°C and increasing more quickly at Tmax > 30°C (Fig. 1). City-wide net present values (NPV) and benefit cost-ratios (BCR) were calculated for the combination of green and white measures. Overall, all cities resulted in positive outcomes of the NPVs and BCRs, and the mortality reduction valuation resulted in the largest (61-71%) of the benefits. BCRs of Mödling, Klagenfurt and Salzburg were estimated at 1.62, 1.55 and 3.43, respectively.

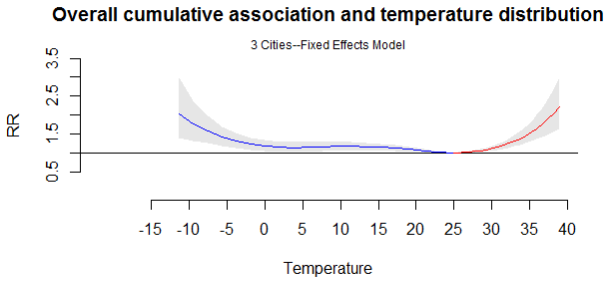

Fig. 4. Association between temperature and all-cause mortality maximum temperature against relative risk.

Conclusions. Even in small and medium-sized cities, high temperatures and the UHI effect play a significant role regarding damages to society. However, urban climate modeling in the three cities has demonstrated a capacity to mitigate this effect with a combination of green and albedo-increasing measures. In all of the three cities, the benefits to society of investing in green and white measures outweigh the costs in city-wide implementation. Given the high benefit valuation of reduced heat-related mortality risk, larger societal benefits may accrue and costs may be reduced by targeting implementation in areas prone to high heat stress.

Productivity and welfare effects of large-scale agricultural investments: Assessment for smallholders neighbouring estates in Malawi

Julian Joseph, Vienna University of Economics and Business, Austria
Email: julian.joseph@s.wu.ac.at
IIASA Supervisors: Tamás Krisztin (ESM) and Michiel van Dijk (ESM)

Introduction. The spillover, wage and market effects of large foreign and domestic investments in agriculture in Sub-Saharan Africa (SSA) can reduce or boost productivity, income, wealth and poverty of local smallholder farmers. Findings from theory and previous empirical work which guide policymakers have lately shifted to more heterogeneous outcomes no longer confined to the positive productivity effects created by spillovers. Recent descriptive evidence for Malawi shows negative effects of estates on smallholders' value of agricultural production (Deininger and Xia, 2018). In this study we use new data to examine the economic outcome effects of investments in estates to assess whether they create benefits or detrimental effects beyond the investing enterprise.

Methodology. Survey data (World Bank LSMS-ISA) for smallholder farmers is combined with a new approach for identifying large-scale agricultural investments using OpenStreetMap data validated with external sources. Using the characteristics of farmers and their farms we match similar farmers within and outside a varying distance threshold around estates. After matching on the propensity score for estate establishment and additionally adjusting for bias resulting from heterogeneity of smallholders, the matched data is used to obtain estimates for Average Treatment Effects (ATT) and corresponding standard errors.

Results. The productivity effects of large-scale agricultural investments on their small-scale neighbours are heterogeneous and vary with crops. While there is strong evidence for negative impacts of estates on maize yields, non-staple crops exhibit positive or insignificant ATTs. Field sizes are negatively affected for maize. The combination of these results for maize shows that the negative effects of estates outweigh the inverse relationship of yields and farm size for the cultivation of this crop among SSA farmers. Given the importance of maize as a staple for Malawian small-scale farmers the productivity loss is also likely to cause the observed significant reduction in value of agricultural production for the estate neighbours. These cannot be outweighed by the increased wage income in proximity to investment sites leading to negative or insignificant effects on total income. Poverty and (livestock) assets are unlikely to be impacted by estates while there is some evidence for more diversification of crops cultivated.

Conclusions. This study shows that positive productivity spillovers from estates to smallholders tend to only materialize for some cash crops while the staple crop maize is very likely negatively impacted by estates. This limits the applicability of the classic spillover argument for large-scale investments especially coupled with the limited income impacts and not affected poverty reduction. Policies addressing the investment framework for new and existing agricultural investors should carefully consider means of utilizing the increases in diversification, productivity of a limited set of crops and possibly wage labour to mitigate the negative effects on maize yields and total household income.

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Modelling to increase the yield and eco-efficiency of cropping system in the North China Plain

Liu Zitong, China Agricultural University, China
Email: lztsicau@163.com
IIASA Supervisors: Rastislav Skalsky (ESM) and Juraj Balkovic (ESM)

Introduction. Producing sufficient maize and wheat crops in a sustainable way to feed its large population of over 1.4 billion is grand challenges in China (Godfray et al., 2018). The North China Plain (NCP) is the most important wheat and maize production area in China, producing about one-thirds and two-thirds of China's total wheat and maize output (FAO., 2016). Although its productivity has been constantly increased, the sustainability of the cropping system has been increasingly questioned due to the high resource use and negative environmental impact (Wang et al., 2008). This paper combined field data with scenario modelling to investigate the productivity, resource (water and nitrogen) use efficiency and environmental impact in NCP. The aim is to explore potential options to increase the yield with higher eco-efficiency in the future, i.e. producing more grain with less water and N inputs and less negative impact on the environment.

Methodology. The EPIC model was used to simulate grain yield, and water and nitrogen use efficiency of spring maize and the winter wheat-summer maize rotation at the study site. Crop variety and cultural practice parameters used for the EPIC model were calibrated using 10 years experimental data from Quzhou (QZ) comprehensive Experimental Station. With the calibrated EPIC model, the performance of the three crops was simulated under different nitrogen and water scenarios from 2007 to 2017. Grain yield, water and nitrogen uptake, N loss were simulated to analyses the systems productivity and environmental performance in response to irrigation and nitrogen inputs and chose the optimal inputs.

Results and Conclusions. Spring maize and the winter wheat-summer maize rotation in North China Plain allows highly efficient use of resources (climate, water and nitrogen) to achieve high yield. A simulation modelling based systems approach enabled the quantification of productivity and environmental impact of the system in response to water and nitrogen inputs. 180 mm of irrigation water and 180 kg/ha of nitrogen for spring maize, and 360 mm (180 for wheat and 180 for maize) of irrigation water and 390 kg/ha (240 for wheat and 150 for maize) of nitrogen for rotation are required to maintain the potential productivity of grain yield at 11t/ha and 18 t/ha respectively, and to have minimum impact on the environment. These rates are lower than those practiced by many of the local farmers, indicating potential for improved management. The approach used and the results generated in this paper can help to quantify the eco-efficiency of the system and to develop management strategies for advancing crop yield while reducing the negative impact on the environment.

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Environmental benefits related to carbon sequestration after land use change

Lilit Ovsepyan, Institute of Physicochemical and Biological Problems in Soil Science, Russian Academy of Sciences, Russia
Email: lill.ovsepyan@gmail.com
IIASA Supervisors: Anatoly Shvidenko (ESM) and Dmitry Schepaschenko (ESM)

Introduction. Most land use changes significantly affect the amount of carbon (C) sequestered in vegetation and soil, thereby, shifting the C balance of ecosystems. Ongoing on 220 million hectares worldwide, the abandonment of agricultural lands is an important phenomenon triggered by both ecological and socio-economic reasons. In the Russian Federation, a massive cropland abandonment was caused by the collapse of the Soviet farming system in early 1990s and now about 40 million ha (or ca. 50% of the currently cultivated area) is remain unused. Abandonment of agricultural land leads to the substantial C sequestration in vegetation and soils and their self-restoration and development towards zonal natural ecosystems. Therefore, agricultural abandonment may be a significant and low cost strategy for carbon sequestration and mitigation of anthropogenic CO2 emissions due to the vegetation recovery and increase in soil organic matter content.

Methodology. This research was based on analysis of published and our own experimental data of abandoned soil properties in former USSR area. The C stock and C accumulation rate were calculated according to C content, soils depth, soil bulk density and age of self-restoration. As a part of ecosystem services of abandoned lands, the C balance was calculated.

Results.
The C stock increase was observed for abandoned lands in all bioclimatic zones of Russia. The C accumulation rate was the highest during first 10 years of abandonment (2.3 ± 0.6 Mg C ha^{-1} $year^{-1}$) and decreased achieving 0.86 ± 0.24 Mg C $ha^{-1}year^{-1}$ according to the age of self-restoration from 10 to 60 years and was the lowest for age after 60 years (0.14 ± 0.034 Mg C $ha^{-1}year^{-1}$). The qualitative changes also included the decrease of soil bulk density and temporal and spatial features of plant successions towards complex forest or steppe natural ecosystems. All together it leads to increase the carbon sink.

Conclusion.
The C stock increase is related to complex processes impacted by climatic conditions, the initial state of the former arable land, the productivity of the formed plant communities, age of self-restoration and specifics of zonal plant successions.

Energy system planning with endogenous fuel price: a bilevel game after the Paris Agreement

Yoga Wienda Pratama, Imperial College London, UK
Email: y.pratama18@imperial.ac.uk
IIASA Supervisors: Piera Patrizio (ESM) and Ping Yowargana (ESM)

Introduction. COP21 in Paris led to ambitious targets to limit the average global temperature increase. This may lead to a dramatic change in our energy system and a rapidly diminishing demand for fossil fuels in the future following the technology cost learning of intermittent renewables technologies (IRT) at the given fixed fuel price. In the real world, however, the fossil fuel industry has the flexibility to strategically change its production rate and price to maximise its profit, which may strongly affect the pace required to achieve the decarbonisation targets. As such, the role of negative emissions technologies (NETs) may become even more important in the future.

Methodology. In this study, the cost of both IRT and fossil fuel, i.e. natural gas, are dynamically evaluated in the electricity system optimisation model with endogenous technology cost learning (ESOXEL) and in a multi-leader-common-follower bilevel game approach using model for inter-regional energy trading (MIRAGE), respectively. In the bilevel game approach, fossil fuel producers from different regions which have bigger bargaining power in the global energy system are set as leaders while the energy system, in this study is the UK electricity system, is set as follower. Fossil fuel producers have the flexibility to determine their pricing strategy to affect optimal natural gas demand from the UK electricity system to maximise their profit.

Results. This study found that flexible thermal plants have a high value as they provide a wide range of ancillary services, e.g. dispatchable power, flexibility, etc., in the decarbonised electricity system. If the decarbonisation is done by rapidly reducing the demand of natural gas and heavily relying on IRT, the market-pool left for the fossil fuel industry is highly valuable natural gas, which demand is inelastic to the fuel price. Therefore, the optimal strategy for the fossil fuel industry is increasing the prices which, in turn, increase the cost of providing ancillary services for the electricity system. However, if natural gas demand declines gradually and NETs are allowed to mop up the residual emissions, the demand for natural gas becomes more elastic to the price. Consequently, the optimal strategy for the industry is to keep the price of natural gas moderate which can lower the cost of providing the grid ancillary services.

Conclusions. The common approach considers only technology cost learning of IRT and neglects the dynamic behaviour of fossil fuel price. In this study, we found that the dynamic behaviour of the fossil fuel industry in responding to the risk of rapidly diminishing demand after the Paris Agreement is critical. Not only it can slow down the rate of decarbonisation by lowering the price to attract more demand, but it can also strongly affect the cost of providing critical services (e.g. ancillary services) for the energy system. This study also found that NETs will play a crucial role, not only in mopping up residual emissions but also in indirectly preventing the excessive cost of the critical services associated with fossil fuel utilisation.

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Improving evidence-based modelling of forest management patterns

Katharina Schulze, Vrije Universiteit Amsterdam, The Netherlands
Email: k.schulze@vu.nl
IIASA Supervisors: Dmitry Schepaschenko (ESM) and Steffen Fritz (ESM)

Introduction. Afforestation and short rotation woody plantations (SRWPs) have numerous advantages such as provisioning of wood and biomass, carbon mitigation, erosion reduction and increase of land value, especially in marginal agriculture land. Due to such advantages and increasing demand for biofuels, SRWPs are expanding. However, they often rely on intensive technologies and are commonly characterized by dense rows of single species, impairing biodiversity compared to natural forests. Aim of this study is to create spatial-explicit data on where SRWPs can and will occur, in order to understand their full potential, impact and consequences.

Methodology. Evidence data on SRWP locations was provided by the Geo-Wiki campaign on human impact on forests and we compared 3 methods for determining suitability. First, values of significant predictors were classified as unsuitable, suitable and very suitable, based on the data distribution within the SRWP points. As the second and third method, we predicted suitability by applying a binary logistic regression and a Random Forest classification with a 10-fold cross-validation. In total, 11 predictors describing soil, climate and terrain were included, based on the literature, availability of global data and scenarios for the future.

Results. Temperature and water availability were identified as most important predictors for the suitability of SRWPs, followed by terrain conditions. Soil conditions had a significant impact on SRWP occurrence, but the magnitude was comparably lower. For all methodologies, South-East Brazil, Eastern China and Southern Australia were recognized as prominent high suitability areas (Figure). On average, the total extent of at least moderately suitable areas (>0.4) was around 13Mio. km^2, excluding protected areas, primary forests and critical habitats, which covered 13%. About 20% of areas with moderate to severe soil erosion loss were in locations with at least moderate suitability. The resulting spatial patterns are largely in parallel with suitable land cover data used in GLOBIOM with differences in Eastern Europe and Western Asia.

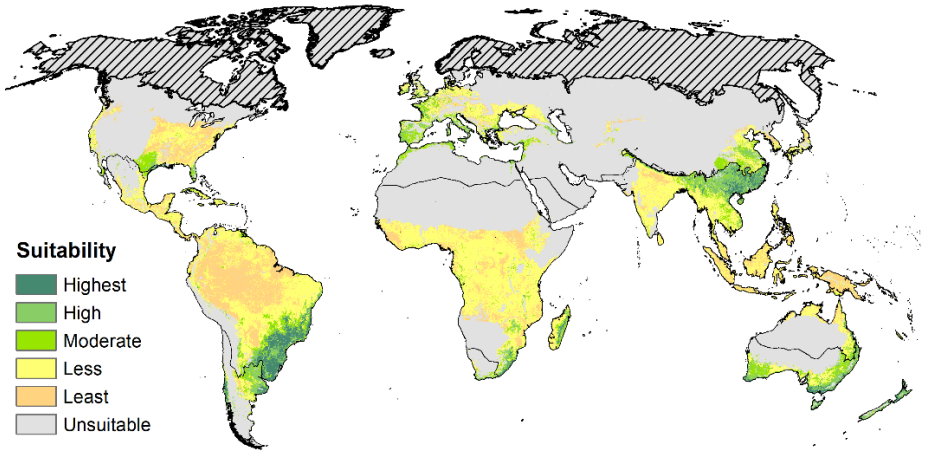

Figure: Average result of predicted short rotation woody plantation suitability combining three methodologies. Note: boreal forests are not

Conclusions. This study highlights the importance of spatial-explicit data on SRWP suitability for global change studies, including biodiversity and land degradation assessments. Our choice of predictors enables us to create future suitability scenarios, which will be helpful for assessing future potential and impacts. Consequently, other important variables, such as accessibility or economic return, were not included since scenarios for those are not available.

Ecosystem effects of boreal N fixation by bryophytes

Gabriel R. Smith, Stanford University, USA
Email: grsmith@stanford.edu
IIASA Supervisors: Oskar Franklin (ESM) and Florian Hofhansl (ESM)

Introduction. The ability of trees to remove carbon (C) from the atmosphere positions forests as crucial components of climate change mitigation plans (*1*). To predict the capacity of a forest to buffer global change pressures like elevated atmospheric CO_2 (eCO_2), we need to know how forest productivity will be affected by these same changes. Boreal forests cover a large portion of the Earth's land surface and store about 272 Pg of C (*2*), forming a central nexus of the global C cycle. Their ability to grow in response to eCO_2 may be constrained by the availability of key nutrients (*3*, *4*). A major source of N in boreal forests is N-fixing cyanobacteria that live in symbiosis with understory feather mosses (*5*). As such, the direct and indirect responses of boreal mosses to global change could throttle overall ecosystem nutrient availability, constraining the fertilizing effect of eCO_2 and reducing the boreal carbon sink. However, most work on boreal moss N fixation thus far focuses not on whole ecosystem responses and vulnerabilities, but on controls and extents of N fixation within the understory moss layer (*5*–*7*). To address this knowledge gap, we built a coupled C and N ecosystem model explicitly representing moss N fixation as a primary source of N within the boreal forest. We will subject our model to varying levels of eCO_2 and N deposition to evaluate overall system responses to determine how N fixation by mosses affects the response of boreal forests to multifactorial global change.

Methodology. The model consists of a system of ordinary differential equations representing the major pools of C and N within the boreal forest system, such as trees, soil organic matter, litter, and understory mosses. Photosynthesis by trees and mosses provides new inputs of C, while N fixation by mosses and N deposition provide new inputs of N. Litter produced by trees and mosses decomposes, becoming soil organic matter. Through microbial mineralization, soil organic matter releases inorganic N and C, the latter of which exits the system, while the former enters an inorganic N pool and may subsequently be taken up by plants or leach out. Parameters will be drawn from prior modeling efforts (*8*) and published literature on moss N fixation (*5*, *9*).

Results. Preliminary model runs produced equilibria in most pools after approximately 30 time steps using assigned parameters. Subsequent runs will make use of new parameter sets based on the literature and will assess variation in ecosystem C balance between differing global change scenarios. Further feedbacks, like dependencies on light availability, may be added into the model to increase realism.

Conclusions. Our model will generate new predictions of boreal forest ecosystem responses under global change that take into account understudied components of boreal nutrient and C cycles. Our approach decomposes the overall ecosystem response into the individual contributions of different dynamics and thereby helps to focus subsequent research efforts on factors with significant uncertainty that may have an unexpectedly large influence on observed changes.

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Policy-relevant simulations on co-firing biomass for electricity in Vietnam

Hoang Anh Tran, University of Science and Technology of Hanoi (USTH) – Vietnam and Vietnam Initiatives for Energy Transition (VIET), Vietnam
Email: tranhoanganh2808@gmail.com
IIASA Supervisors: Piera Patrizio (ESM) and Juraj Balkovic (ESM)

Introduction. The current Vietnamese national plan for power development states that more than 35 coal plants will be in operation over the next decade, providing around 268 TWh of electricity by 2030, 47 % of the national energy mix. According to this projection, the Vietnamese energy sector would achieve an average carbon intensity of 0.64 tCO_2/MWh by 2030, equivalent to a 120 % increase in emission in the energy sector alone. In this context, the cofiring biomass with coal for electricity generation is considered as a potential pathway to compromise between two conflicting goals: ensuring energy security by exploiting domestic fuel resources while at the same time pursuing the global climate agenda by mitigating the emission of a fossil-based energy sector.

Methodology. This work considers present and future biomass yields, deriving from the biophysical model EPIC, of the three abundant agricultural residues in Vietnam: rice, maize and soybean. These yields are adopted as potential biomass feedstock for co-firing in the spatially explicit, techno-economic model BeWhere. The BeWhere identifies the least-cost supply chain configuration for the Vietnamese coal/co-firing sector in the 2018 - 2030 time span and it is adopted in a recursive and intertemporal dynamic fashion. Both approaches account for the total emissions generated in the system, subject to an endogenous carbon tax which increases throughout time. The defined system in the recursive is restricted to a set of existing plants at the examined year. However, the dynamic model optimizes a larger system of all existing and planned plants from the base year (2018) to 2030. This recursive model was previously developed with only two types of biomass feedstocks – from rice residues (2 RM). This current study improves the understanding on the impact of biomass utilisation in the recursive by adding four other biomass feedstocks (6 RM) (from maize and soybean) and aims to develop the fully intertemporal dynamic one.

Results. In the recursive model, increasing biomass utilization allows to achieve a greater emission reduction: 41 Mt CO_2 (6 RM) vs 33 Mt CO_2 (2 RM) and results in 10% reduction of CO_2 avoided cost. The dynamic cofiring model indicates that 6.3% of biomass share target by 2030 (Renewable Energies Development Strategy) would be warranted with a minimum carbon price of 30 \$/t CO_2eq. Below this price, the system will be more economically feasible to operate with all coal power plants instead of setting up the new cofiring infrastructure. Nearly 87% and 93% of standalone coal plants will be phased out by 2030 with a carbon price of 50\$/t CO_2eq and 70\$/t CO_2eq respectively, equivalent to reduce 38 and 44 Mt CO_2. However, this model shows that the maximum potential, in term of emission reduction, is 18% every year because of the technological limitations (maximum 20% of substitution).

Conclusions. The results show that carbon price is an important incentive for cofiring retrofitting in Vietnam, however, under the envisaged coal power expansion, such measure is not sufficient to reach more ambitious climate goals in the country energy sector. Meeting the 2-degree global warming scenario of the Paris Agreement, translates into more than 40% of emission reduction by 2030, thus radical mitigation options (e.g. fuel switching or carbon capture and storage retrofit) should be considered.

World Population (POP)

Young people's migration intention in Egypt

Amr Abdelwahed, Shanghai university, China
Email:amr_jasser@cu.edu.eg
IIASA Supervisor: Anne Goujon (POP) and Raya Muttarak (POP)

Introduction. North African countries have one of the highest emigration rates in the world (Etling, Backeberg, & Tholen, 2018), as exemplified by Egypt which has a rich and complex migration history because of its geographical location, population structure. The country's population is very young: about two-thirds of Egypt's population is under the age of 30. Investigating future migration intentions as a proxy for future migration behaviors is important since it enhances our understanding of the migration process and consequently allows us to anticipate the policy implications that these intentions may have for the origin and destination countries (Carling, 2004, 2014; Williams, Jephcote, Janta, & Li, 2018). Despite a high rate of international migration of young adults(Farid & El-Batrawy, 2015), the study on migration intention in Egypt is scarce. To this end, this study aims to examine the likely drivers of migration intentions of young people (defined as individuals age 18 to 29) in Egypt, focusing on three sets of drivers: (1) individual demographic and socio-economic characteristics; (2) household characteristics and (3) community characteristics. The analysis is based on the panel data survey of young people in Egypt (SYPE) for 2009 (n= 8488) and 2014 (n=5883), representing time points before and after the 2011 Egyptian revolution. The surveys are nationally representative, covering all governorates in Egypt.

Methodology. Logistic regression models are applied to study the determinants of migration intention to live, study or work abroad of young people in Egypt using a uniform set of variables as explanatory variables. The variables include individual characteristics (gender, age, marital status, education, employment and general health status), household characteristics (gender and age of household head, size and poverty status), and civic participation and community characteristics (participation in voluntary activities and politics, environmental pollution status, and place of residence).

Results. The analysis indicates that respondent's age and gender are highly correlated with the intention to migrate but also the marital status. Overall, young unmarried men are more likely to have a migration intention. As well, respondents with a higher education, who are employed and participate in political and voluntary activities, are more likely to express migration intentions. Pollution levels also affect positively the intention to migrate. The comparison between 2009 and 2014 shows similar patterns, although male respondents show less intention to migrate when they are in school or in employment in 2014 compared to 2009.

Conclusions. The results indicate that those who expressed migration intentions are a selective group in terms of demographic and socio-economic characteristics. Moreover, we found evidence for a distinct relationship between political discontent and young people's aspiration to migrate. Our empirical findings are in line with earlier studies on migration motives, such as those related to the political context, e.g. the role of corruption. While the results of the investigation of the drivers of migration intentions confirm that, the demographic and socio-economic individual characteristics, civic participation and community characteristics are the likely drivers of migration intentions, these relationships should not be interpreted as causal. The next step of the research would look at how these intentions transform into actual international migration.

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On international migration across the Shared Socioeconomic Pathways

Hélène Benveniste, Princeton University, USA
Email: helene.benveniste@princeton.edu
IIASA Supervisors: Jesus Crespo Cuaresma (POP), Raya Muttarak (POP), Matt Gidden (ENE)

Introduction. With climate change, migration patterns are expected to change. This might strongly affect income levels and their distributions across and within countries, energy consumption and greenhouse gas emissions. Yet, migration patterns will likely depend on future global socioeconomic development. The Shared Socioeconomic Pathways (SSP) represent five qualitative narratives of future development (SSP1 to SSP5), useful tools to study heterogeneous futures. Some dimensions of the SSP are expressed in quantified projections of population, GDP, inequality, energy consumption and emissions over the 21st century. The population component reflects explicit, pathway-specific migration assumptions. Yet, migration assumptions are implicitly part of other components. In this project, we explicitly quantify the effects of international migration on several other components (GDP, energy consumption, emissions), by comparing original projections to scenarios of zero net migration.

Methodology. We model GDP projections without migration based on two effects: changed population size, and remittances, i.e. income sent by migrants to their origin country. We base remittances on migrant stocks derived from bilateral migrant flows, modelled with a gravity model calibrated to 2017 data on country-level population size, per capita income and distance between capitals. We produce energy consumption and emission projections for five combinations of SSP narratives and climate policy scenarios, based on our zero-migration population and GDP projections, with special attention to negative emissions rescaling.

Results. We find that the effect of migration assumptions on all components is highly country-specific and can be substantial. Most interestingly, we find that the world on average is richer with migration for SSP1 (sustainability), SSP2 (middle of the road) and SSP4 (inequality), but poorer with migration for SSP5 (fossil-fuel). SSP3 (regional rivalry) sees little change, as it originally includes low levels of global migration. These differences in income translate into higher world energy consumption with migration for all SSP, but lower world emissions for SSP1. At a country level, while in general migration leads to higher income and emissions, in densely forested countries migration does not necessarily reduce income yet decreases emissions by increasing negative emissions (e.g. Brazil, Mexico).

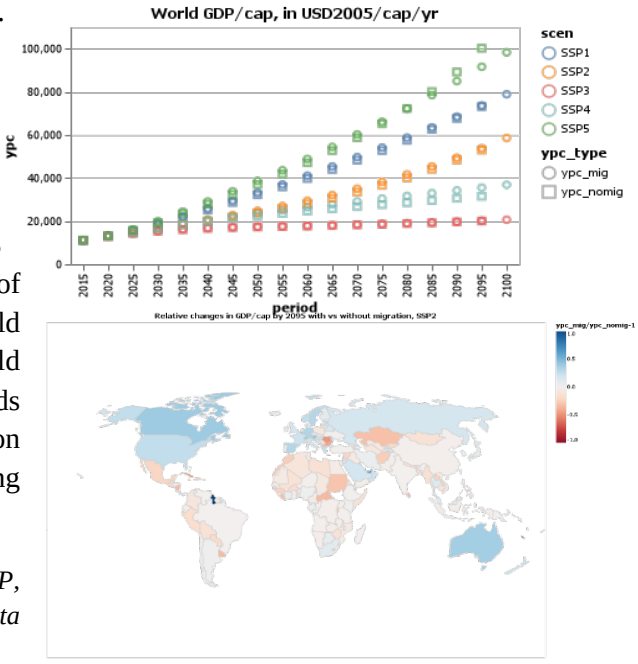

Figure: World GDP per capita projections with and without migration for 5 SSP, in 2005 US dollars per capita (top). Relative change in country GDP per capita with vs without migration by 2100 for SSP2 (bottom).

Conclusions. This study strongly suggests that any one-size-fits-all approach to projecting future international migration in a climate change context can be highly misleading. In order to make sensible policy decisions, a better understanding of the coevolution of migration and climate change is warranted. Our new zero-migration projections, when used as inputs in IAM-type models of migration dynamics, can serve as crucial tools to explore interactions between migration and climate policies.

Health co-benefits of air quality improvements in India under climate change mitigation and air quality abatement policies

Asya Dimitrova, University Pompeu Fabra, Spain
Email: asya.dimitrova@isglobal.org
IIASA Supervisors: Guillaume Marois (POP) and Gregor Kiesewetter (AIR)

Introduction: Rapid socio-economic development in India has been accompanied by gains in life expectancy and improvements in a range of health outcomes. However, it is uncertain how the fast pace of urbanisation, the aging of the population and climate change will alter this trend in the future. Demographic changes have a direct implication for future health risk assessment as they alter baseline population and mortality as well as the relative proportion of vulnerable individuals in the population. This study estimates the health co-benefits from projected changes in ambient air pollution in India up to 2050 and under alternative climate change mitigation and air quality abatement scenarios, considering future demographic change and urbanisation trends.

Methods: A multi-dimensional cohort-component projection model is employed to explore dynamically over time the range of potential health impacts across urban and rural areas in all states of India. Population data are drawn from the five-dimensional demographic projection for India under SSP2, developed by KC, et. al. (2018). Future exposures to ambient fine particulate matter ($PM_{2.5}$) are derived from the GAINS model based on projections for emissions and economic activities under the MESSAGEix-GLOBIOM integrated assessment model (IAM) framework. Age-specific exposure response functions are drawn from the most recent epidemiological literature. We considered a combination of three scenarios for climate change mitigation, corresponding to the countries´ current Nationally Determined Contributions and the long-term goals of 1.5°C and 2°C as defined by the Paris Agreement, and two scenarios for $PM_{2.5}$ abatement, corresponding to current Indian legislation, and current European legislation on air quality control, respectively.

Results: More ambitious climate mitigation and air quality abatement policies bring clear improvements in life expectancy, number of premature deaths and years of life lost. Although health co-benefits of emission reductions are very compelling, comparison across scenarios demonstrates that maximum benefit for human health occurs when targeting air pollution explicitly. The distribution of the regional health burden of $PM_{2.5}$ shows that regions with lower projected exposure and more developed regions with low baseline mortality will experience greatest improvements in health outcomes.

Conclusions: Investments in more stringent air quality control measures could bring considerable health co-benefits in the medium term across all climate mitigation scenarios. Unlike conventional approaches, modeling the impacts of environmental exposures dynamically, by considering the change in the size and structure of the population, and spatially, allowed us to reduce one of the main areas of uncertainty in projections of health impacts under climate change. Results could be used to inform the design of efficient and spatially explicit adaptation and mitigation strategies.

Education or economic status? Comparing their relative effect on prime-age adult death in India using longitudinal survey

Moradhvaj, Jawaharlal Nehru University, India
Email: moradhvajiips@gmail.com
IIASA Supervisor: Wolfgang Lutz (POP) and Erich Striessnig (POP)

Introduction. Improvement in the health status of the population is closely related to its level of socio-economic development. Several studies emphasized on the relationship between mortality and socio-economic status measured through importance of occupation, income, wealth and education (Pamuk, Fuchs & Lutz 2011; Lutz, Kebede 2018). However, research seeking to understand the relationship of education and economic status of individuals with adult mortality is an unexplored phenomenon in developing countries. This study examines relative effect of two primary aspects of development, education and economic resources on prime age adult mortality in more comprehensive way than has been done before in India.

Methodology. Using the data from a national sample of 115781 Indian adults aged 15-59 years form India Human Development Survey (IHDS) of wave 1, conducted in 2004–2005 and wave 2, conducted in 2011–2012, this study analyses the relative effect of educational attainment and economic status on prime age adult deaths between 2004-05 and 2011-12 in India. Using the two-level logistic regression model accounting clustering with in the communities, we have estimated the independent effect of educational attainment and economic resources measured at individual and community level on prime age adult mortality.

Results. Around 3% adults died in prime age group between 2004-05 and 2011-12, while the percentage of male dying is higher compared to females. Education level and economic status at individual level have significant effect on prime adult's death with simultaneous adjustment for economic status and education level along with other predictors. The decline in the risk of prime age adult death with increasing education level is greater than the decline associated with rising wealth quintile. Community level education is apparent to reduce the risk of dying among females, Female residing in a community with higher average level of education remains independently associated with a significant reduction in the risk of mortality, while average wealth quintile at community level does not have significant effect. Interaction analysis between education level and economic status show that the probability of prime age adult death decline with increasing the level of education with similar pattern across all economic groups. Meanwhile, the risk of death does not change among similar level of education with the increasing of the economic status.

Conclusions. Effect of education attainment reduction on the likelihood prime age adult mortality is highly significant and greater than economic status in India. The pattern founded in this study suggests that education should be considered as policy priority for improving the adult mortality in developing countries like India. A further research can be done to explore the possible pathway through which the education attainment and economic status affect the prime age adult mortality.

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Physical, psychological, and cognitive functioning: A generalised structural equation model

Paolo Miguel Manalang Vicerra, Chulalongkorn University, Thailand
Email: pmvicerra@gmail.com, pmvicerra@alum.up.edu.ph
IIASA Supervisors: Sergei Scherbov (POP) and Wolfgang Lutz (POP)

Introduction. Life expectancies across societies have generally been increasing over recent decades. As more people reach higher ages, burden of diseases and decline in health functions become issues. Physical, psychological, and cognitive health dimensions have been observed to affect each other, but these have been done in such ways that one health dimension is an outcome while the others are the determinants. It is important to view the three health dimensions simultaneously to test their relationship and mechanism.

Methodology. Health measures are examined using the cross-sectional survey 2016 Population Change and Well-being in the Context of Ageing Societies (PCWAS). A part of the survey data was gathered people aged 60 years and over. The sampling involved a multi-stage approach where stratifications have geographical and administrative bases. Restrictions were imposed and the resulting analytic sample is 6,301 persons.
Generalised structural equation modelling is used to explore the relationship between physical, psychological, and cognitive tasks of numeracy and memory; collectively known as the principal cognitive functions. Latent variables are constructed to establish the measures for physical and psychological health where the latter is tested if it is a mediating variable. Model-fit statistics are central to determine which has better fit between cognitive functioning tasks; whether it is memory, numeracy, or when integrated into principal cognitive functioning.

Results. Physical function as a latent construct has a significant direct effect on both cognitive performance outcomes as well as when taken collectively [Numeracy (SC = -0.53, $p<0.001$), Memory (SC = -0.52, $p<0.001$), Principal cognitive function (SC= -0.60, $p<0.001$)]. This significance in relationship is observed also with psychological state. The indirect effect of physical function with numeracy and memory performances through psychological function are also observed to be significant. In reference to the total effect, psychological function and physical function overall have a significant relationship with the cognitive performance outcomes. The model for the integrated cognitive tasks domain of principal cognitive function is observed to have the lowest value with regard to AIC, BIC, and log likelihood indicating a better model fit rather than modelling the individual cognitive tasks.

Conclusion. Constructing latent variables using combinations of health measures had been demonstrated to be significant for both physical and psychological health functioning. This is important to assess their respective integrated relationship toward cognitive performance tasks and how they may affect each other simultaneously within the context of later-life adults.
There are limitations to this study including the data being cross-sectional among others. Regardless, this study has shown that other modelling methods can be used which can exude the complexity of health dynamics. For further studies, social factors can be tested for inclusion in the model particularly those involving human capital.

Risk and Resilience (RISK)

Structuring emergence: How does law impact the emergence frontier for nature-based solutions to enhance urban resilience?

Regina M. Buono, The University of Texas at Austin, USA
Email: regina.buono@utexas.edu
IIASA Supervisors: Joanne Linnerooth-Bayer (RISK) and Wei Liu (RISK)

Introduction. Cities around the world are experimenting with nature-based solutions (NbS) to address social-environmental issues but many have been slowed or stymied by various uncertainties and ambiguities, including the effectiveness of chosen solutions, institutional paralysis, and questions of legal compliance. NbS are widely advocated for, especially in tackling climate change challenges, yet they have not been systematically implemented or mainstreamed. To facilitate human adaptation to climate change and address other environmental challenges, the law must allow a society to adopt and bring to scale novel and experimental solutions. This study seeks to understand how law affects the implementation of NbS for urban environmental issues and to explore how and under what conditions might an adaptive governance setting better support their use.

Methodology. This research employs a qualitative case study approach on a city adopting NbS, which consists of an analysis in NVIVO software of semi-structured interviews with key actors implementing NbS in Valladolid, Spain, and an analysis of relevant legal and policy authorities (laws, regulations, ordinances, development codes, agreements, and reports). The analysis uses the State-Reinforced Self-Governance Framework developed by DeCaro et al. (2017), which extends and complements Ostrom's (1990) institutional design principles using identified legal design principles, to understand the "emergence frontier" of adaptive governance in highly regulated environments.

Results. A number of constraints and facilitating factors related to law and regulation were identified. The constraints include (1) a lack of explicit legal authorization for NbS, which contributes to decision-makers' reluctance to adopt them; (2) strict water quality regulations that do not contemplate non-traditional or innovative methods may impede some solutions that could be suitable in select circumstances; and (3) bureaucratic hurdles related to procurement law and concerns about the fiscal and management efficiency of solutions that deviate from the norm. The facilitating factors include (1) flexibility (undefined standards and lack of prohibitions on NbS) in the law that grants actors room to maneuver; and (2) a polycentric governance structure that brings EU/national policies to act as regulatory drivers that encourage local entities to opt for NbS, and provide legal and political cover to local innovators.

Conclusions. The laws governing Valladolid, Spain, can be navigated successfully to facilitate the implementation of NbS in that city, but doing so requires political will and great effort on the part of decision-makers. Amending laws at all levels to recognize NbS conceptually and authorize space and processes for experimentation, and familiarizing civic employees with the solutions, may facilitate their uses.

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Unilateral climate policies in a North-South stock-flow consistent model

Nepomuk Dunz, Vienna University of Economics and Business, Austria
Email: nepodunz@web.de
IIASA Supervisors: Thomas Schinko (RISK) and Asjad Naqvi (ASA)

Introduction. The 2015 Paris agreement requires countries to substantially curb greenhouse gas (GHG) emissions in order to keep average global temperature increases below 2°C. However, current countries' commitments are insufficient, and a global concerted effort seems increasingly unfeasible. At the same time, unilateral climate policies (UCPs) raise concerns over deteriorating economic competitiveness in a globalized world economy. So called "North-South" models analyse potential consequences of such UCPs. However, a more comprehensive understanding of all transmission channels and resulting feedback effects of UCPs requires macroeconomic models with a financial dimension, embracing climate transition risks and investment opportunities.

Methodology. We conceptualize a two-sector North-South Stock-Flow consistent (SFC) model to analyse the role of trade integration, financial transfers and investment flows in response to UCPs. This allows us an evaluation of potential winners and losers as well as respective trade-offs and provides insights for the design of such policies in practice. The model consists of multiple sectors in each region – three representative firms (brown and green energy producer, final good producer), a representative household, a government and a bank - with the standard SFC specification that every inflow has an outflow counterpart within the model. Next to labour and capital, firms need to choose between fossil-based or renewable energy as an input factor for production. Further, they decide whether to import intermediate goods or producing them domestically. This setup allows the assessment of financial, economic and distributional feedback effects of UCPs; a key advantage of the SFC framework.

Results. We assess four distinct UCP scenarios - *1)* a unilateral carbon tax in the North *2)* additionally a unilateral border adjustment tariff (BAT) in the North *3)* additional de-risking of green investments in the South and *4)* carbon tax in the North and de-risking in the South without the BAT. All four scenarios are aiming for a 25% global emission reduction by 2030 compared to a baseline scenario. Since we currently abstain from explicitly modelling climate damages, a carbon tax in the North has detrimental effects for global GDP (Fig.1). An additional BAT in the North deteriorates global GDP even further, however, the North region is relatively better off than the South region (Fig.2). De-risking green investments in the South lowers global low-carbon transition costs, having the least detrimental effects for global GDP.

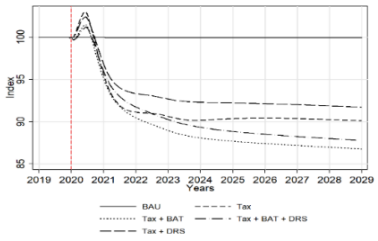


Fig.1: Global GDP

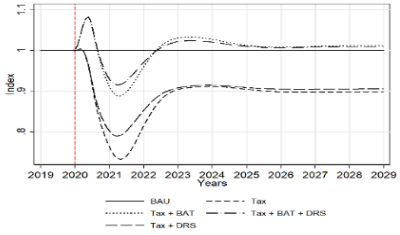


Fig.2: Relative GDP North vs. South

Conclusions. Our model simulations suggest that UCPs could be environmentally effective despite carbon leakage resulting from intersectoral and international spill-over effects, given a high level of trade and financial integration (e.g. EU). The climate policy portfolio for dealing with different externalities (carbon, trade and transition risk) determines whether the implementing region would relatively loose out or benefit from its economic competitiveness. Furthermore, mobilizing cross-border green investments could help smooth the economic effects of the low-carbon transition.

Governance of riverine cities: The water-related risks for Guwahati City

Safa Fanaian, University of Oxford, UK
Email: safa.fanaian@some.ox.ac.uk
IIASA Supervisor: Wei Liu (RISK) and Mikhail Smilovic (WAT)

Introduction. Majority of the world's populations will reside in cities, with one million in the global south. These cities are characterized by low service provision, inadequate infrastructure, high climatic risk, complex local politics, and layers of overlapping policy. Many such cities stand on rivers. As rivers often flow beyond city jurisdictions, water-related risks are governed by local, state and national departments. There is a dearth of studies that longitudinally explore complex polycentric governance processes of water-related risks for riverine cities. Guwahati city in Northeast India and its rivers were studied, as it is an emblem of urbanization on the Brahmaputra River. Water-risks explored include urban floods, inadequate water supply, and wastewater released into rivers. This research explores how the composition and functioning of water risk governance systems evolved as the city grew and its implications for resilience of the riverine city in an uncertain world.

Methodology. The evolution of water-related risks and its governance is explored through combined insights from Historical Institutionalism and Multi-Level Perspective. The approach explores political influences along with interactions across multiple levels of governance (national, state and local) from 1969-2018. Data used includes local daily newspaper (1970-2019); archived documents until 1980, government and NGO reports, thesis' and policy documents. The longitudinal analysis is split into four periods: 1969-1980 political reforms; 1981-200 economic and urban institutional reforms; 2001-2014 city rejuvenation and modernization; and 2015- present Smart City Directive. Examination for each period is carried out in the following pattern: external and internal pressures on policy, policy developments; effects of policy; and feedbacks of policy changes.

Results. The study showed that, while the colonial structure of governance was inherited by the city of Guwahati the functions and mode of operation were distinctly marked by local culture and context. The structure and functions have over time expanded to include more actors and institutions. This trend towards increased polycentric arrangement is seen for flood management where the institutions involved from 1969 to 2018 increased from two to 24, for water supply the increase is from four to six, the least being wastewater from one institution to three. This trend is reflective of government priorities and correlates to public/media pressures. While the climatic patterns have not significantly changed, risk exposure and damage have increased due to changing the land-use pattern and increase in population density.

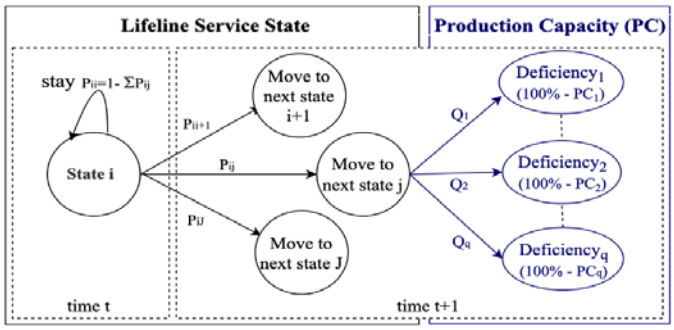
Conclusions. Compositional polycentric arrangement relates to an increase in the number and diversity of actors. The desired form of governance is when institutions start to significantly collaborate towards a functionally polycentric system. The designed hierarchy of water-related risk governance in Guwahati has grown to involve more actors and institutions to address water risks showing characteristic of polycentric arrangement only. The lack of effective collaboration is demonstrated by challenges in regular delivery of service and water risk mitigation. However, this diversity allows the system to withstand minor political and climatic instability.

Post-disaster recovery in industrial sectors: A Markov process analysis of multiple lifeline disruptions

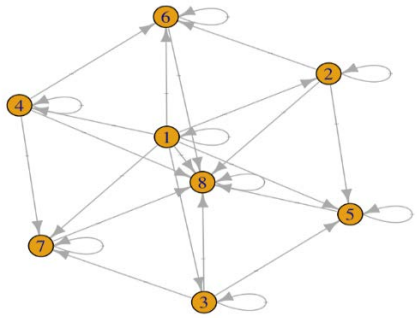
Huan Liu, Kyoto University, Graduate School of Informatics, Japan
Email: huan.liu.53m@st.kyoto-u.ac.jp
IIASA Supervisors: Georg Pflug (RISK), Stefan Hochrainer-Stigler (RISK) and Muneta Yokomatsu (RISK)

Introduction. When faced with lifeline services disruptions, business losses increase even if there is no direct damage caused by disaster. Studies have been done to estimate long-term impacts of a single lifeline disruption on the economy based on hypothetical disaster business survey data or expert-opinion-based estimations, but empirical evidence for how multiple lifeline disruptions impact post-disaster recovery is still lacking. This research is aimed at filling this gap by quantitatively estimating the economic impacts of multiple lifeline disruptions using survey data on firms following the 2011 Great East Japan Earthquake.

Methodology. This research develops a model that combines an estimation of the duration of the lifeline states transition and the transition's impact on production capacity recovery (Figure a). We apply the Markov process to describe the interdependence between lifeline services disruptions. Taking the estimated day-by-day, non-homogeneous transition matrixes as inputs (Figure b), we derive the distribution of the number of days necessary for full recovery and calculate the expected number of days until full recovery, the expected economic losses of a firm in any given lifeline service state, and initial damages.



(a) Model design



(b) Markov Transitions between Lifeline States

Results. We find that 71.27% of lifeline state transitions occurred within 14 days after the earthquake, which implied relatively high resilience of lifeline systems. Restoration of electricity showed the highest influence on production capacity improvement: 15% per day on average compared to 10% per day for gas restoration and 8% per day for water restoration. If electricity is available, priority should be given to gas, which provides 4% daily improvement in productivity, over water, which provides 2% daily improvement. More severe initial damages lead to higher expected losses, but the impact on expected recovery days was not significant. In addition, firms need, on average, 14.2 days to achieve full productivity recovery after achieving full recovery of lifeline services.

Conclusion. Recovery strategy should prioritize reconstruction of higher impact lifelines in both pre-disaster planning and post-disaster reconstruction processes. The model proposed offers businesses and policymakers empirical evidence to support better reconstruction strategies regarding resource allocations.

Prototype of social-ecological systems resilience using system dynamics modelling

Bruno Meirelles de Oliveira, São Paulo University, Energy and Environment Institute, Brazil
Email: bruno.meirelles@usp.br
IIASA Supervisors: Wei Liu (RISK) and Brian Fath (ASA)

Introduction. According to modern resilience thinking socio-ecological systems (SES) work properly within certain ecological and social limits. If these limits are passed, it results in a system regime change with increasing uncertainties, which impacts the reliability of delivering ecosystem services (ES). Modelling a socio-ecological system as complex and adaptive is a crucial tool to inform responsible governance that tackles ES management. A prototype SES resilience model was built to assess the understanding and application of the principles that underpin resilience which could benefit from the formalization of their dependences and dynamics and learn about the benefits of making quantitative assessments of such socio-institutional principles.

Methodology. Multiscale Integrated Model of Ecosystem Services – MIMES (Boumans et al., 2015) is a SES modelling system using system dynamics that embraces various complexity attributes in an interdisciplinary, integrated model. This approach has widely been used to help decision making from an ecosystem services' perspective. Constructing a causal loop diagram integrating the seven resilience principles (Biggs, 2015), revealed the necessity to include a social perspective in the model. Social perspective was captured using Cultural Theory. Eight different types of ecosystem services were extracted from the ecological part of the simulation and combined with the seven resilience principles into the Dynamic Resilience Index (DRI) using a Cobb Douglas-type production function that captures substitutability among factors (Boumans *et al*., 2015).

Results. Numerical simulation produced dynamic representations of the DRI index. Egalitarians showed higher values for resilience in the latter period of the simulation (3 years); Individualists showed the least values of all except in the latter period of the simulation when hierarchists presented lower DRI value. Hierarchists showed greater values for resilience in the beginning of the simulation, but this feature was eroded in the latter period. Fatalists presented the higher values in the simulation but considering that part of their results comes from random functions, the results and its comparative position are still uncertain.

Conclusions. Adopting the SES perspective for resilience and measuring it with DRI shows that the prevalent cultural solidarity of the governance process can be highly influential to the resilience of the system. Such values and beliefs will constrain goals desired for the system and consequently the management, institutions and its behavior. Thus, the four social solidarities presented different behavior for the DRI which points to the necessity of an adaptive governance system that is able to shift behavior through time.

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Boumans, et al ecosystem services 12 (2015), p.30-41.

Trade-offs between urban and agricultural water use: Examining the lessons learnt from the 2015-2018 drought in the Western Cape, South Africa

Simone Pretorius, Stellenbosch University, Stellenbosch, South Africa
Email: PretoriusS@arc.agric.za
IIASA Supervisors: Stefan Hochrainer-Stigler (RISK) and Sylvia Tramberand (WAT)

Introduction. Between 2015-2018 the Western Cape in South Africa experienced a multi-year severe drought. The drought negatively impacted both rainfed and irrigated agriculture as well as the metropolitan city of Cape Town. The Western Cape has a sophisticated water supply scheme which provides water for both urban and agricultural activities. However, storage capacity in the "Big 6" dams were reduced to 20% by the summer of 2018 and the possibility of Day Zero, they day the city's taps would run dry was projected for late April. Local and provincial government implemented several coping strategies including increasing supply and managing demand. The drought highlighted the inter-connectedness of the urban/agriculture water supply and in effect the potential for competition between the two industries. This research aimed to understand the resilience of the two sectors through the five capitals approach as well as the interactions between the capitals and sectors in aiding or reducing resilience.

Methodology. The study made use of the Five Capitals of Sustainability Framework to assess the resilience of the urban as well as rainfed and irrigated agriculture sectors during the 2015-2018 drought in the Western Cape. Rainfed agriculture was represented by wheat while irrigated agriculture was represented by apples. We divided our analysis into the five types of capitals; financial, natural, social, human and physical capital and use indicators for each capital such as GDP, farm profits, rainfall, dam storage, social cohesion, trust, skill of the labor force and access to experts.

Results. Urban industries suffered the severest impacts of the drought. Irrigated agriculture had less severe impacts and they made use of water budgets regarding when and which blocks to irrigate in order to maximize water use efficiency. Rain-fed agriculture showed significant drop in yield, yet quality was high, which allowed farm profits to remain stable. For the Western Cape drought physical capital was determined to be the most important factor in alleviating drought risk, however, when physical capital fails other forms of capital saved the Western Cape from Day Zero. For the urban sector, social capital was pivotal through the reduction in urban water demand as well as the network with the Groenland Irrigation board which donated three weeks' worth of water to the city. For agriculture, the access to experts helped as farmers were advised on water budgets and crop management which kept yield quality and farm profits stable. Some of the lessons learned during the drought included; water will always be prioritized for urban use in times of drought, better collaboration within government is important, the city should diversify their water resources through technology such as desalination and finally changing the behavior of citizens can really help in reducing demand and risks associated with drought.

Conclusions. The Western Cape was able to avoid the worst-case scenario during the 2015-2018 drought. However, all sectors of the economy suffered impacts of the drought. Social and human capital were pivotal in lowering demand and reducing the impacts of the drought on the province. Finally, the city needs to use the current good rains to strengthen drought resilience building on the lessons learnt from the 2015-2018 drought.

Transitions to New Technologies (TNT)

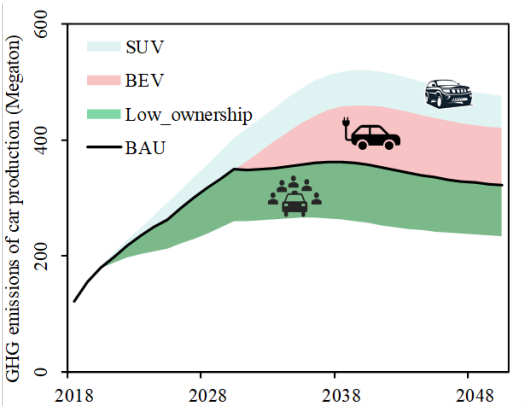
Material and climate implications of the automobile transitions in China: a dynamic material flow analysis approach

Wu Chen, University of Southern Denmark, Denmark
Email: wuc@kbm.sdu.dk
IIASA Supervisors: Arnulf Grübler (TNT), Volker Krey (ENE) and Paul Kishimoto (ENE)

Introduction. Sustainable mobility transition is a key challenge for the global resource, energy, and climate issues due to the interplay with other systems. China has been the biggest producer and consumer of automobiles for over 10 years, but the automobile ownership is less than one quarter of the per capita level in the U.S. by 2017. Consumer preferences continue to evolve: the market share of SUVs tripled to 41.7% between 2011 and 2017. The combined effects of increased ownership, electrification and changing preferences in China will affect future mobility demand for material and energy. This research explores materials demand and carbon emissions relevant to production of new automobile fleets under the transition of technology improvement and consumer preference.

Methodology. We develop a dynamic material flow analysis (MFA) model that specifies four body types (i.e., sedan, MPV, and SUV, and crossover) and four powertrain technologies (i.e., internal combustion engine vehicle (ICEV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and battery electric vehicle (BEV)) of automobiles in China from 1950 to 2050. Detailed bottom-up data such as automobile stocks, market shares, emissions and energy intensity of automobile production from life cycle assessment are combined to analyse future demands for eight materials and embodied carbon emissions from automobile production (including material extraction) under different automobile transition pathways.

Results. To reach current Japanese automobile ownership level in 2050, annual material demands increase and are stable around (22.0 million ton (Mt)) regular steel, (10.8 Mt) high strength steel, (3.4 Mt) iron steel, (5.1 Mt) wrought aluminum, (0.6 Mt) cast aluminum, (1.9 Mt)copper, (0.7Mt) lead-acid battery, and (7.0 Mt) lithium battery after 2025. Such a pathway based on basic electric and SUV scenarios would cause approximately 10.1 Gt carbon emissions from material extraction and automobile production. The automobile manufacturing only accounts for 5.3% of carbon emissions related to automobile production. Carbon emissions from material extraction are mainly in lithium-ion batteries (35.0%) and cast aluminium (27.9%). Our scenario analysis shows continuing popularization of SUV in the automobile market could increase automobile production emissions over the baseline by 14.7%, while ambitious BEV deployment could increase emissions by 16.5%. Automobile production emissions could decrease by 28.3% if lowering the ownership level.



Conclusions. The Chinese automobile fleets are still very young, therefore recycling materials from retired automobiles is not enough to satisfy material demand for new automobile fleets in the short term. Scrapped materials from retired automobiles would offset part of material demand and would help to decrease carbon emission of automobile production after 2040. Pursuing a more comfortable life (e.g., SUV popularization) and ambitious BEV deployment would lead to more carbon emissions in automobile production. Lowering automobile fleets demand would be a more efficient way to lower the carbon emission of automobile production.

Using district heating for storing renewable excess electricity in an 80% demand reduction scenario

Jakob Knauf, Konstanz University of Applied Sciences, Germany
Email: jakobknauf@web.de
IIASA Supervisor: Arnulf Grübler (TNT)

Introduction. New district heating networks are currently built in Germany because they can lower emissions on the short run due to higher energy conversion efficiency compared to many other modes of heat supply. On the long run, reducing emissions through decreasing urban heat demand up to 80% until 2050 is necessary so that climate mitigation goals are meet. However, reducing demand can cause that the operation of the underlying grid-bound infrastructure becomes uneconomic due to lower energy sales. In this work, I focus on how a cross-sectoral approach opens possibilities for new income streams that could mitigate financial losses, which ultimately weakens the threat of creating stranded assets when district heating networks are shut down before end of lifetime because of uneconomic performance. The paper draws on findings from a GIS based simulation model, which used a real case study as object of interest. I show that using existing district heating networks as heat storage for renewable excess electricity can be a feasible option for creating new income streams, if sufficient renewable excess electricity is available and heat demand reduction does not exceed 60%.

Methodology. New district heating systems are currently built in Germany due to their lower emissions compared to other mode of heat supply. It is expected that these networks will also exist in 2050 due to their long lifetime. Using a GIS based simulation model, I (a) size a fictive district heating network similar to one that could be built today for a real urban layout and its current heat demand, (b) calculate the financial loss for a range of heat demand reduction rates (up to 80%) and (c) asses the boundary conditions under which storing renewable excess electricity can help to operate district heating networks economically viable despite of fewer energy sales.

Results. The analysis of the findings show that energy sales under an 80% demand reduction scenario are too low for operating a network that is planned for current demand. Using existing district heating systems as heat storage for renewable excess electricity can create a new income stream that could buffer some financial losses that result from decreasing energy sales. In this sense, the former cause of uneconomic operation, an oversized network and its high thermal mass, turns into a benefit. The application of storing renewable excess energy is limited by the amount of available renewable excess energy and the heat reduction rate. Storing is only economically viable with enough renewable excess energy (1500 full load hours) and a maximum of 60% heat reduction. The maximum total stored heat energy surpasses the actual heat demand if the heat demand reduces more than 60%.

Conclusions. Declining heat energy demand affects supply networks like district heating systems to a high extent because their utilization decreases, which reduces financial gains that are needed to cover fixed costs. Leaving sectoral approaches (electricity, heating) and open district heating for sector coupling might create new revenue streams for existing infrastructures. Furthermore, using renewable electricity in heating instead of fossil fuels that currently power many district heating networks reduces emissions. However, storing requires sufficient amounts of renewable excess electricity, policies that reward their use and adequate electricity transport networks, which makes a comparison of using district heating networks with other means of storing and demand side management approaches necessary in future.

Analysis of electric vehicle adoption in Shanghai: based on empirical data and agent-based simulation

Xingrong Zhao, East China University of Science and Technology, China
Email: zhao08031219@126.com
IIASA Supervisors: Tieju Ma (TNT) and Arnulf Grübler (TNT)

Introduction. Adopting electric vehicles (EVs) is considered as an important solution to reduce fossil fuel dependency in transportation section. China has become the world's largest market for EVs with strong support from the Chinese government. This study aims to reveal how consumers' demographic characteristics (including age, gender, education, occupation, income, family size, number of children and administrative regions) as well as peer-effect influence EV adoption. This study is expected to give implications for decision makers to make better future possible policies for promoting the adoption of EVs and inform the automobile industry what kind of vehicles would be welcomed by consumers, especially in the city of Shanghai.

Methodology. This study first conducted a question survey in Shanghai, and 1750 useful answers were obtained. Based on the survey results, this study uses Discrete Choice Model (DCM) to investigate the influence of demographic characteristics on EV adoption. In the DCM, consumers' demographic characteristics are taken as predictive variables for regression analysis and obtain characteristics that have a greater impact on EV-adoption. Based on the DCM, this study identifies different consumers' EV-adoption probability. Then this study develops an agent-based model (ABM) involving DCM and peer-effect. In the ABM, peer-effect will influence consumers' probability of adopting EVs. With agent-based simulation and the empirical survey data, this study investigates the impact of peer-effects on EV adoption and predicts the future dynamic market shares of pure battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) in Shanghai under different scenarios.

Results. Our results show that among all demographic characteristics, age, income, education, family size, number of children, and residential location have significant impacts on consumers' EV adoption. Consumers with higher education, higher income, and living in downtown are more likely to buy EVs, while those with larger family size and older ages are less interested in EVs. Through the simulation results of ABM, we find that the peer effect can accelerate the adoption of EVs. With more friends buying EVs, consumers will be more inclined to adopt EVs. In addition, we also studied the impact of EV social ownership, Shanghai free-license policy for EVs and the technology maturity of EVs on consumer purchasing decisions. Different scenario analysis show that the cancellation of the free-license policy will slow down the adoption of EV quite a lot, but with the continuous advancement of EVs, consumers will gradually show more interests in EVs and continue to buy EVs.

Conclusions. Consumers' EV adoption is a complex process affected by many factors. Analysis with the ABM has demonstrated that by implementing the free-license policy and improving EV technology will effectively promote the popularity of EVs. Peer effect, as another important factor that can promote the adoption of electric vehicles, should be valued by the government and enterprises. It may be a good choice to increase publicity in some densely populated communities or enterprises.

Water
(WAT)

Concurrent temperature and precipitation shifts in historical and historical natural-only model simulations

Felicia Chiang, University of California, Irvine, USA
Email: chiangf@uci.edu
IIASA Supervisors: Peter Greve (WAT), Ted Veldkamp (WAT) and Yoshihide Wada (WAT)

Introduction. Concurrent droughts and heatwaves have serious impacts across many sectors and have become increasingly common in recent observations. In addition, droughts have been observed and projected to warm at a faster rate than the average climate in the southern U.S.. In response to these joint dry-warm and conditional warming patterns, we evaluated the impact of climate change on concurrent monthly low precipitation and high temperature events.

Methodology. We empirically calculated the joint probability of extreme temperature and precipitation events (i.e. temperature above the 90^{th} percentile and precipitation below the 10^{th}) using the Gringorten plotting position. From these results, we compared 'shifts' of concurrences in historical (with anthropogenic forcing) and historical natural-only (without anthropogenic forcing) simulations which allow us to attribute these differences to climate change. Then, using copula theory, we fitted copula families to precipitation and temperature data from select locations from the globe. From the fitted multivariate distributions, we sampled probability density functions (PDFs) of temperature given specified precipitation conditions. Using PDFs from historical and natural-only simulations, we calculated conditional probability ratios representing changes in temperature exceedance probabilities.

Results. In our initial findings, low precipitation occurrences have experienced increases in the tropics in historical simulations, while high temperature occurrences have increased worldwide, with the greatest shift in the mid-latitudes. Much of the global land area has experienced large increases in compound precipitation and temperature extremes in historical models, while no coherent shift is shown in historical natural-only models. In historical models, the global median of precipitation and temperature concurrences is 2.5 times higher than natural-only simulations at the end of the 20^{th} century. From one of our select locations in the Midwestern United States, we also found that the conditional probability ratio of exceeding a 2^{o}C temperature anomaly is 1.37, indicating that the probability of exceeding this temperature anomaly is greater in the historical scenario relative to the natural-only.

Conclusions. From these results, we have gained a better understanding of the widespread nature of the impact of climate change on concurrent droughts and warm spells. In addition, through our conditional framework, we have provided a new way of accounting for underlying moisture conditions while assessing the impact of climate change on temperature exceedances. This framework can be applied to other multivariate relationships and allow us to measure conditional risks and attribute those risks to anthropogenic climate change.

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Evaluating irrigation development under environmental change taking into consideration water-energy-food nexus interactions: Case of Malawi

Fortune Faith Gomo, University of Dundee, Scotland
Email: ffgomo@dundee.ac.uk, fnyatsanza@gmail.com
IIASA Supervisors: Barbara Willaarts (WAT) and Michiel van Dijk (ESM)

Introduction. The Malawi Irrigation Policy targets to double land under irrigation from 110 000 hectares in 2015 to 220 000 hectares by 2035. With 80.6 % of water withdrawals going to irrigation, making it the biggest water user, it is imperative to understand the implications of planned irrigation developments on catchment and national water resources, as well as the food and energy sectors.

Methodology. We carried out an agricultural water footprint (WF) analysis in Malawi at catchment level for ten catchments in the Zambezi river basin, taking into account the irrigated crop distribution of Malawi. We then used the method proposed by Hoekstra *et al*. (2011) and Willaarts *et al*. (2019) to estimate the WF and irrigation water demands (WD) of eight irrigated crops; as well as the effective rainfall, P_{eff} of northern, central and southern Malawi, using 2010 as the baseline. We also analysed the WF under projected climate conditions up to 2050. The agricultural WD were then evaluated against the net available water resources within each catchment, based on the Community Water Model actual runoff model outputs. The annual agricultural *WF* was estimated by considering the total amount of water consumed by crops in each month in irrigated areas.

Results. Total annual WF for Malawi will increase by 129 % between 2010-2035 under baseline conditions. The highest increase was in the Shire catchment. Catchments with large-scale irrigation schemes, face large monthly irrigation water deficits in the baseline during the dry season; whereas catchments with more smallholder irrigation are likely to able to meet all their irrigation WD. With increased irrigation area, assuming the same crop distribution, irrigation water requirements would increase significantly, even in the wet season. Catchments that did not face deficits in an average year, would face deficits with an increased irrigated area.

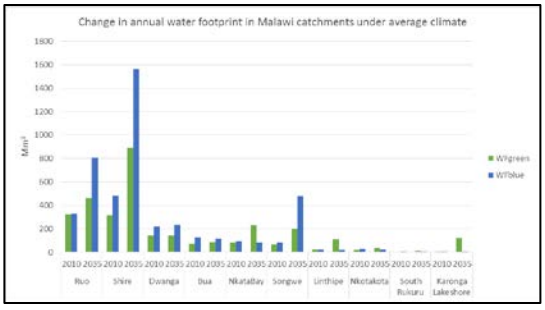

Figure 5: Change in annual WF in Malawi catchments under baseline conditions.

Conclusions. Results showed that irrigation WD will increase with an increase in irrigated area in the catchments in Malawi, by up to 200 %. The highest WF will come from catchments with large scale commercial irrigation, compared to catchments with mostly smallholder irrigation. This has huge implications as it means that cash crops, mostly for export, will compromise water security in the country with associated impacts for food and energy sectors. However, when evaluated against net water availability, irrigation water deficits will be experienced in all catchments.

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Trade openness and groundwater use and depletion of nations

Paul Ruess, University of Illinois at Urbana-Champaign, USA
Email: ruess2@illinois.edu
IIASA Supervisors: Taher Kahil (WAT) and Yoshihide Wada (WAT)

Introduction. To contribute to the debate over globalization and the environment we ask the question: what is the impact of trade openness on national groundwater use and depletion? We address this question using econometric methods to quantify the causal relationship between trade openness and groundwater use and depletion of nations on a global scale. We further explore this causal relationship for some crop-specific groundwater use and depletion.

Methodology. Groundwater depletion is calculated as the difference between groundwater abstractions and groundwater recharge, both of which are modeled globally at 30 arc-min resolution using the Community Water Model[1] for the years 1961-2014. Groundwater is further attributed to 26 different crops by separately calculating volumetric irrigation crop water demands globally. Using a 2-stage least squares instrumental variables approach, we then instrument for trade openness using geographic variables. Further, we exploit time-series variation of trade agreements to go beyond a cross-sectional analysis, enabling us to use an unbalanced panel of countries for the time period. Panel data enables us to use fixed effects and better control for unobservable heterogeneity.

Results. For the years 1961-2014, we find that a one percentage point increase in trade openness leads to a 3.16% increase in groundwater depletion. These results are not statistically significant, with a p-value of 0.2. This conflicts with previous, statistically-significant results showing that trade openness decreases irrigation water use in agriculture (on average).[2] We also quantify the causal impact of trade openness on groundwater depletion of the 26 different MIRCA crops individually. These results are in progress and will hopefully be reported during the presentation. Furthermore, during this analysis, daily crop factors for all 26 MIRCA crops were generated (Figure 1), which may be used to improve crop irrigation accuracy in the CWatM in the future.

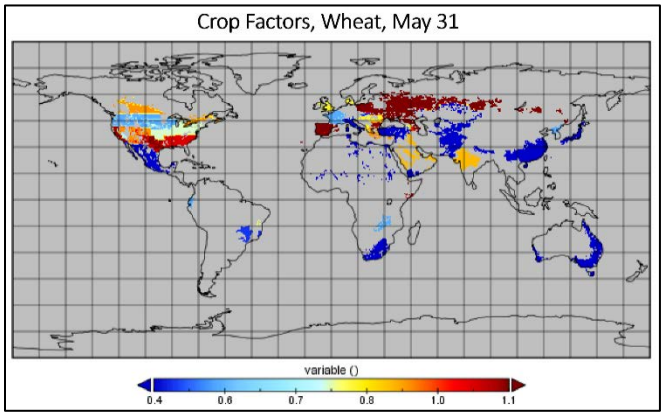

Figure 6. Crop Factors for Wheat on May 31. These values were calculated daily for all 26 MIRCA crops.

Conclusions. This work attempts to understand the implications of trade on groundwater use and depletion, in total and for 26 different globally significant crops. Ultimately this will provide insights into global food markets, showing which crops impact global groundwater depletion. Once completed, this study will have both scientific and policy relevance as we strive to untangle causal relationships in the global food supply chain and determine its environmental impacts.

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Do irrigated bioenergy plantations have a larger effect on water stress than the avoided climate change?

Fabian Stenzel, Potsdam-Institute for Climate Impact Research, Humboldt-University Berlin, Germany
Email: stenzel@pik-potsdam.de
IIASA Supervisors: Sylvia Tramberend (WAT) and Peter Greve (WAT)

Introduction. Bioenergy plantations with carbon capture and storage (BECCS) are a negative emission technology widely used in climate scenarios for the 21st century. Many scenarios assume negative emissions to compensate for residual and past emissions in reaching ambitious climate targets (1.5°C). Hejazi *et al*. showed in 2015 for the United States, that contrary to the general perception that climate change mitigation improves water conditions, irrigated bioenergy could further increase water stress in comparison to the mitigated climate change effects. We take this question at the global scale and compare water stress within two experimental setups: a world with active climate engineering through BECCS resulting in only moderate global warming at end-of-century temperatures around 1.5°C (RCP2.6) and one without BECCS in a warmer climate of ~3°C (RCP6.0).

Methodology. For consistent climate, land-use and water demand input data, we utilize the ISIMIP2b database which provides input based on four different global circulation models. The plantation areas for bioenergy follow the narrative of SSP2, together with irrigation parameters from recent BECCS literature. Scenario simulations are performed with the dynamic global vegetation model LPJmL. We use the Water Stress Index (WSI), which is defined as the ratio of human water demand to natural water availability (discharge). The water demand includes withdrawals for irrigated agriculture (food, feed and bioenergy) and projections of the future water demand for households, industry and livestock. Additionally, we analyze how strict compliance to the regional planetary boundary of freshwater by respecting environmental flow requirements (EFRs) would influence water stress.

Results. Our results show that mean, as well as maximum yearly water stress in 2095 will strongly increase in RCP2.6 and RCP6.0 compared with today, especially in already vulnerable regions. The global area sum of regions with a WSI of 40-100% in the yearly maximum [mean] increase from 1954 [955] Mha today to 2639 [1443] Mha in RCP6.0 and 3452 [1903] Mha in RCP2.6. To compare the two future scenarios, we sum up the maximum [mean] water stress indices weighed by population and find that RCP2.6 with irrigated bioenergy compares to RCP6.0: 62.5 | 37.5% [59.25 | 40.75%]. Respecting EFRs reduces the water stressed area in RCP2.6 by 20% (to approximately RCP6.0 levels).

Conclusions. We conclude that assessed at the global level climate mitigation via BECCS might exert similar, if not higher water stress than the avoided climate change. The reduction of other climate change impacts (sea level rise, glacier melting, ocean acidification, etc.) thus comes at the costs of additional water and plantation area demand, should BECCS be used as a negative emissions technology. The impacts, however, can be reduced but not completely avoided, if EFRs would be respected. Additionally, the results of this study can be used to identify optimal locations for BECCS. Together, optimal locations and strict water policies have the potential to reduce both, water stress and climate change impacts to a minimum.

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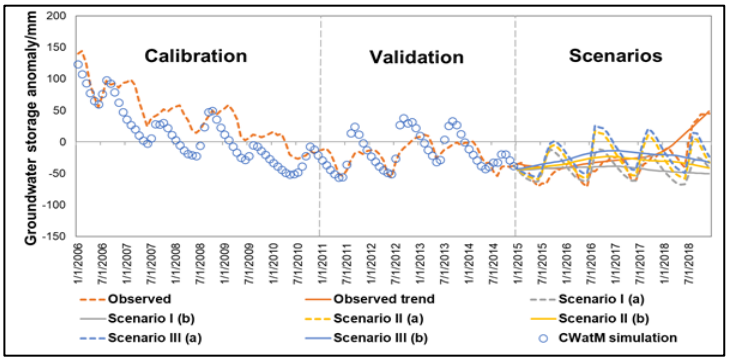
Evaluation of groundwater recovery in the North China Plain

Wenting Yang, Tsinghua University, China
ywt16@mails.tsinghua.edu.cn
IIASA Supervisors: Peter Burek (WAT) and Yoshihide Wada (WAT)

Introduction. The North China Plain (NCP) has experienced severe water shortages over the last several decades. To ensure food security and domestic water use, groundwater has been largely overexploited, resulting in significant groundwater depletion at a rate of ~1 m/yr. To mitigate the water crises in North China, the South-to-North Water Division (SNWD) project was launched in 2002. The SNWD has profoundly altered the structure of water supply and water use and brought an important historic opportunity for groundwater recovery in the NCP. Climate variability and suppression of agricultural water use also contribute to groundwater recovery in recent years. Here we take China's capital of Beijing as a case study.

Methodology. First, we set up the high-resolution Community Water Model (CWatM) of 30 arcsec (~1 km at the equator) spatial resolution to simulate groundwater storage. Water use of domestic, industrial, and agricultural sections is considered to represent the water demand and simulate the interactions with water availability (i.e., surface water and groundwater). Second, monthly groundwater storage is taken to calibrate the model using two objectives: (1) correlation coefficient and (2) difference of changing trend between simulated and observed groundwater storage time series. Third, three scenarios are set to quantify contributions of (1) increased precipitation, (2) transferred water, and (3) suppression of agricultural water use to groundwater recovery during 2015–2018. Fourth, the 2D groundwater model USGS MODFLOW is coupled with CWatM to simulate pumping and lateral flow of groundwater.

Results. Correlation coefficient between simulated and observed monthly groundwater storage for calibration period (2006–2010) and validation period (2011–2014) is 0.88 and 0.65, respectively. Simulated groundwater depletion rate for calibration and validation period is -25.2 mm/yr (observed -25.6 mm/yr) and 2.0 mm/yr (observed 0.1 mm/yr), respectively. Observed groundwater storage increases at a rate of 17.9 mm/yr during 2015–2018, with contributions from increased precipitation of 19.8 mm/yr (39%, Scenario I), transferred water of 16.4 mm/yr (32%, Scenario II), and suppression of agricultural water use of 14.5 mm/yr (29%, Scenario III). CWatM coupled with MODFLOW can better simulate the groundwater storage change with higher correlation coefficient of 0.94 (without calibration) during 2006–2010.



Conclusions. Groundwater in the NCP is recovering in recent years due to climate variability, transferred water, and policy. The SNWD may further promote recovery of groundwater in the future which will gradually achieve the planned rate of 9.5 km^3/year at the first stage of the central route project. High-resolution CWatM is applicable to regional groundwater storage simulation incorporating interactions between water demand and water availability. Furthermore, CWatM coupled with MODFLOW can further strength the mechanism of groundwater simulation.

Index

Aishwarya Iyer 24
Alex Nutkiewicz 26
Amr Abdelwahed 43
Asya Dimitrova 45
Bertram F. de Boer 31
Brent Eldridge 15
Bruno Meirelles de Oliveira 53
Carlos Andrés García-Velásquez 32
Chenling Fu 16
Chris Krapu 18
Christine Roxanne Hung 23
Daniel Johnson 34
Fabian Stenzel 63
Felicia Chiang 60
Fortune Faith Gomo 61
Gabriel R. Smith 40
Hanspeter Wieland 19
Hélène Benveniste 44
Hoang Anh TRAN 41
Huan Liu 52
Jakob Knauf 57
Jhonny Villarroel-Schneider 11
Julian Joseph 35
Jun Ukita Shepard 27
Katharina Schulze 39
Lilit Ovsepyan 37
Liu Zitong 36
Manan Bhan 29
Matthew Gibson 22
Minghao Qiu 9
Moradhvaj 46
Muye Ru 10
Nepomuk Dunz 50
Nicolas Choquette-Levy 14
Paolo Miguel Manalang Vicerra 47
Paul Ruess 62
Regina M. Buono 49
Roope Kaaronen 17
Rory Gibb 33
Safa Fanaian 51
Simone Pretorius 54
Stefanie Klose 25
Talita Cruz 21
Wenting Yang 64
Wu Chen 56
Xingrong Zhao 58
Xu Wang 12
Yoga Wienda Pratama 38
Yuyoung Choi 30