YSSP23

A new generation of scientists

Proceedings of the Final Colloquium

Young Scientists Summer Program

IIASA 50
International Institute for Applied Systems Analysis

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

The Proceedings of the Final Presentations comprises summaries of the research results obtained during the YSSP that were presented at International Institute for Applied Systems Analysis, Laxenburg, Austria, on 25 August 2023.

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Proceedings Editors: Caesar Agula, Yuheng Cao, Markus Dörflinger, Nadine-Cyra Freistetter, Mengxing Joshi, and Brian D. Fath

	August 25, 2023 WODAK Room
9:00 – 9:15	Welcome and Opening Remarks Albert van Jaarsveld, IIASA, Director General Fabian Wagner, Capacity Development and Academic Training, Dean Brian Fath, Young Scientists Summer Program, Scientific Coordinator
	Session 1
09:15 – 09:40	Mengxing Joshi - Who got lonelier during the COVID-19 pandemic? Evidence from the English Longitudinal Study of Ageing Ann-Christine Link - The tail end of migration: Assessing the climate resilience of migrant households in Ethiopia Dhruba Ghimire - Population projection for tracking social dimension SDG targets and indicators at subnational levels in Nepal Markus Dörflinger - Past and future migration in Asia: The (potential) impact of migration on population ageing Rajdeep Singh - Optimal vaccine allocation strategies
09:45 – 10:10	Caesar Agula - Socio-demographic heterogeneity in cost of accessing medication abortion: insights from Ghana Shiya Zhao - Climate mitigation effects on poverty and household expenditure: consumption commodity heterogeneity in a global energy model Judy Xie - Exploring more socio-politically credible coal and gas phase-out pathways Lucas Vivier - A comprehensive model for policy design and evaluation in the housing sector Yisheng Sun - Co-benefits of China reaching carbon neutrality: how they accelerate air quality improvement towards WHO Air Quality Guidelines
10:15 – 10:40	Carmen Séra - South-South technology transfer. Barriers and enablers for a sustainable energy transition Francesco Semeria - Reducing food losses to improve sustainability in transformation pathways for the agri-food system in Sub-Saharan Africa – modelling impacts across the water, energy, food nexus Jin Li - A spatially explicit study on the decarbonization pathway of China's iron and steel industry. Jintea Kim - The net zero transition and role of energy trade in northeast Asia Takuya Higashitani - Integrated diffusion modeling of bidirectional chargers, electric vehicles, and rooftop photovoltaics
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14:30 – 14:55	Nihar Chhatiawala - Transboundary flow regime management in the Ganges-Brahmaputra Basin system under hydro-climatic uncertainty María D. Castro–Cadenas - Downscaling global socio-political scenarios for the Western Mediterranean Sea to test nature-based solutions within an ecosystem-based approach Ifedotun Aina - Economic and environmental implications of alternative water policies for drought adaptation in South Africa Huiying Ye - Linking R&D investment to emission reduction cooperation: overcoming free-riding while achieving deep de-carbonization Haoyu Wang - Integrating time series data with epidemiologic models to improve prediction of COVID-19 dynamics in China
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15:50 – 16:15	Ehsan Pashanejad Silab - A functional connectivity approach for exploring interactions of multiple ecosystem services in the context of agricultural landscapes Anais Ostroski - A systems-based approach for modelling and assessing pollination provision networks in agricultural landscapes Or Elroy - Fighting misinformation in social media Reihaneh Bandari - Knowledge co-production and assessment of local actions for the achievement of locally relevant socioeconomic and environmental Sustainable Development Goals Jalal Awan - Citizen science at work: A four-stage framework for advancing policy change with crowd-sourced air pollution data

END OF PRESENTATIONS:
YSSP RECEPTION IN CONFERENECE AREA

Contents

Population and Just Societies (POPJUS)

Who got lonelier during the COVID-19 pandemic? Evidence from the English Longitudinal Study of Ageing

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Introduction. Loneliness has adverse impacts on mental and physical health, particularly for the older population. Disease control measures during the COVID-19 pandemic potentially amplified feelings of loneliness. This study based on longitudinal data aims to answer the following questions: 1) Did older adults in England get lonelier during the pandemic? 2) What are the different patterns of loneliness trajectories among older adults? 3) What demographic factors, general risk factors, pandemic factors and protective factors contribute to the distinct trajectories observed?

Methodology. This study uses Wave 8 (2016-2017), Wave 9 (2018-2019), COVID Wave 1 (Jun-Jul 2020), and COVID Wave 2 (Nov-Dec 2020) of the English Longitudinal Study of Ageing. The sample consists of 4,492 individuals aged 50+, who participated in all four waves, and answered questions related to loneliness. The methodology uses multilevel binary logistic regression, latent class growth (LCG), and multinomial logistic regression (MLR). With MLR, we examine the association between the latent class membership and four groups of predictor variables, namely demographic factors (i.e., age, gender, ethnicity and urban/rural status), general risk factors (i.e., wealth, employment, self-rated health, and depression), pandemic factors (i.e. worries and huge lifestyle change, having two and more COVID symptoms, and self-isolation), and protective factors (i.e., pray/meditate daily, partners' emotional support, CASP quality of life, and change in oral and written social contacts).

Results. The loneliness prevalence increased consistently: 15.4% in Wave 8, 16.5% in Wave 9, 19.7% in COVID Wave 1, and 20.5% in COVID Wave 2. The loneliness odds in COVID Wave 1 are significantly greater than in Wave 9. The LCG analysis identified four heterogenous loneliness trajectories: 79.3% stayed not lonely, 9.8% became lonely, 4.8% became not lonely, and 6.1% stayed lonely. While including all four groups of predictors in MLR, younger adults (aged 50-74) were more likely to become lonely and stay lonely compared to older adults (aged 75+). While only including demographic predictors, men were less likely to stay lonely than stay not lonely. These gender differences were no longer significant when general risk and pandemic factors were taken into account. Furthermore, the link was reversed when protective factors were included - women were less likely to stay lonely. Unexpectedly, non-whites were more likely than whites to become not lonely than stay lonely. The significant risk factors for becoming lonely were retirement, good self-rated health and depression. Worries about the pandemic reduces the probability of staying not lonely. However, this factor is no longer significant once significant protective predictors (i.e., partner's emotional support and higher CASP) are included.

Conclusions. Loneliness prevalence increased significantly during the pandemic, but most of the studied population remained not lonely. The worries and huge changes in lifestyle due to the pandemic are risk factors for increased loneliness. Such pandemic impacts could be mitigated by stronger emotional support of the partner and better quality of life. The pandemic did not create loneliness but rather revealed pre-existing social and health disparities. Dismantling barriers and fostering social ties of older adults should be a priority, regardless of the presence or absence of a global pandemic.

The tail end of migration: assessing the climate resilience of migrant households in Ethiopia

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Introduction. Climate change is associated with increasing frequencies and intensities of extreme weather events. These can, directly and indirectly, shape human (im)mobility (Black et al. 2011). While most research on migration focuses on climate as a migration driver in origin areas, there is a gap in knowledge on the role of migration for climate resilience in the destinations (Kuschminder et al. 2018). In this study, we assess the well-being impacts of climatic shocks and explore differences in the resilience between migrant and non-migrant households at migration destinations in Ethiopia, a country not only highly exposed but also vulnerable to climatic shocks.

Methodology. We use three waves of longitudinal data from the Living Standards Measurement Study conducted by the World Bank (2011-2016). The data contain information on households' migration histories, shock exposure, and well-being. We construct a well-being index (WBI), which consists of seven equally weighted dimensions (education, health, food, economics, assets, infrastructure, and housing). The impacts of climatic shocks (droughts, floods, heavy rain, and landslides) on well-being over time for migrant and non-migrant households are modelled using fixed effects panel regressions. Further explorative mediation analyses yield insights into the mechanisms explaining differences in resilience among the households in Ethiopia.

Results. Exposure to climatic shocks negatively affects well-being but with considerable differences across households. The negative impacts are particularly strong for migrant compared to non-migrant households, suggesting differences in their resilience (Figure 1). While migrant households experience fewer climatic shocks and also have an overall higher well-being compared to non-migrant households, they suffer more than twice as high well-being impacts when exposed. On the other hand, we find that migrant households can better cope with health and price-related shocks. In additional analyses, we show that climatic shocks influence migrants' well-being by negatively affecting food security, health, and access to basic infrastructures. Different mechanisms explain the larger climate burden experienced by migrant households. Mediation analyses suggest that differences in the age, education, and sex composition between migrant and non-migrant households explain the former's lower climate resilience. Major differences in shock impacts can also be observed by regions of origin and destination.

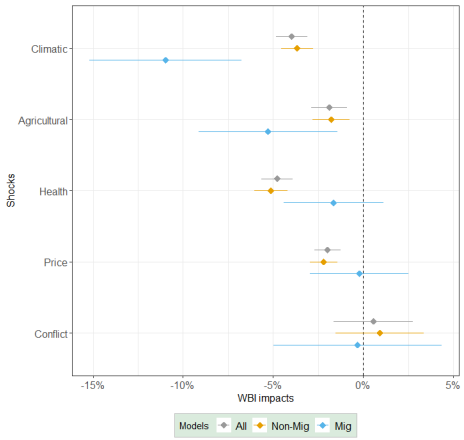

Figure 1: Impact of shocks on well-being (all, non-migrant and migrant households).

Conclusions. This research is highly relevant to policy. It improves the understanding of underlying factors shaping differential climate change impacts and supports targeted interventions to increase the well-being of vulnerable populations.

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Population projection for tracking social dimension SDG targets and indicators at subnational levels in Nepal

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Introduction. Population projection is a way to imagine a future, provides a potential future size and age structure of the population based on mid-year population and a set of assumptions of future fertility, mortality, and migration. These projections are widely used for resource allocation and planning at national and subnational levels. The population projection model's output depends on the projection methodology, availability of datasets and indicators, the status of spatial and demographic heterogeneity, level of geographic details, and consistency of the hypothesis related to the future evolution of components of the population dynamics. Therefore, this study aims to understand the demographic dynamics of Nepal at subnational level in the past, and future progression at subnational levels.

Methodology. The quantitative research method has been used to conduct the study. The study is based on the secondary datasets mainly population census and household surveys. The demographic estimates have been derived from the Population Census 2021 and six rounds of the Nepal Demographic Health Survey from 1996 to 2022. The future medium (most likely) demographic scenario for fertility, mortality, migration (international and internal) and the educational transition has been defined and quantified based on the literature review. A multidimensional cohort-component population projection model is used to compute a five-year population projection at the national and province level by using R statistical software.

Results. The population of Nepal has shown a consistent upward trajectory both in the past and is expected to continue in the future. Over the last decade, the total population increased by 2.7 million, growing from 26.5 million in 2011 to 29.2 million in 2021. This growth is primarily shaped due to a higher number of births than deaths, leading to a rapid rise in population. However, the international and internal migration in recent times has caused the overall population increase to be less rapid than anticipated. Both at the national and provincial level, international and internal migration has played a substantial role in shaping future demographics. Furthermore, Nepal is poised to experience "return migration" from labor-exporting countries such as Gulf countries and Malaysia, which has been incorporated in the population projection model.

Conclusions. In this study, the subnational population projection model has been developed to strengthen the demographic evidence-base for planning, programming, and monitoring the development interventions including Sustainable Development Goals (SDGs). The population projection has been carried out for the period of 2021 – 2061 (two generations) at national and province level. It is highly expected that the research yields some newer observations differently in academia per se due to applying novel approach while modelling by incorporating age, sex, place of residence and education as a spatial and demographic heterogeneity. The developed prototype can be replicated to the remaining Low- and Middle-Income Countries (LMICs) where vital registration is poor. Therefore, it can be said in a fine that the present research has great potential in Nepal and the international arena.

Past and future migration in Asia: The (potential) impact of migration on population ageing

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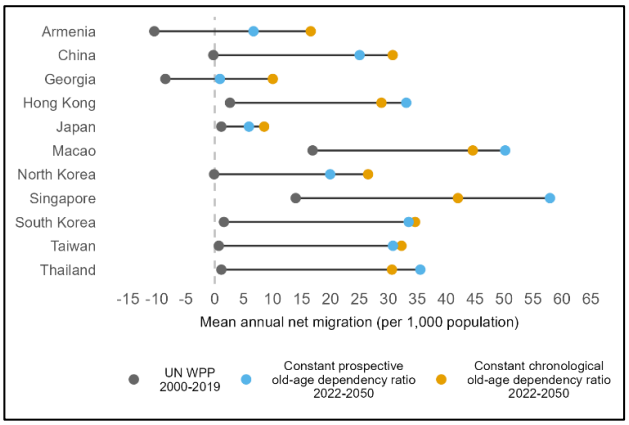
Introduction. Population ageing is a global trend and one of the main demographic challenges of the 21st century. In policy debates, immigration is often discussed as a factor which potentially can slow down population ageing. Several studies elaborated on the interaction between migration and changes in the age-structure mainly in developed countries. As the number of Asian countries experiencing population ageing is rising, this study provides a comprehensive analysis of the recent and the (potential) future impact of migration on population ageing in Asia.

Methodology. Using data from the World Population Prospects 2022 (UN 2022), we decompose changes in the old-age dependency ratio and the size of the working-age population of 51 Asian countries for the period 1990-2020 into the effect of cohort turnover, deaths, net migration and changes in life expectancy. Next, we calculate the number of migrants needed to maintain the old-age dependency ratio and the size of the working-age population for the period 2022-2050. Using a cohort-component model of population projection we estimate this 'replacement migration' for 11 Asian countries in which population ageing is already relatively advanced. In addition to a chronological threshold to define old-age, the prospective threshold is used in all analyses to take into account that life expectancy varies across time and space (Sanderson and Scherbov 2007).

Results. First, we find a considerable effect of recent net migration on changes in the age-structure of countries with highly negative (e.g. Armenia) or positive net migration (e.g. Qatar). However, in many countries this effect is relatively small compared to cohort turnover and deaths. Second, the annual number of migrations needed to maintain the old-age dependency exceeds observed net migration rates in all countries even when using prospective measures of age (see Figure). In both scenarios replacement migration is lower in countries where population ageing is more advanced (e.g. Japan). Third, the number of migrants needed to maintain the size of the (prospective) working-age population is lower than in the constant (prospective) old-age dependency ratio scenarios and seems more realistic in some countries given their recent migration.



Conclusions. Our study reveals remarkable differences among Asian countries regarding both the effect recent migration had on their age-composition and the number of migrants needed to offset population ageing in future. The results show that the number of replacement migrants in a country depends strongly on its current and projected age-structure and the chosen indicator for population ageing. In most of the countries however, higher immigration as the sole solution to offset population ageing does not seem a realistic scenario. Finally, this study underlines the applicability of prospective measures of age in decomposition analysis and the replacement migration concept.

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Economic Frontiers
(EF)

Optimal Vaccine allocation strategies

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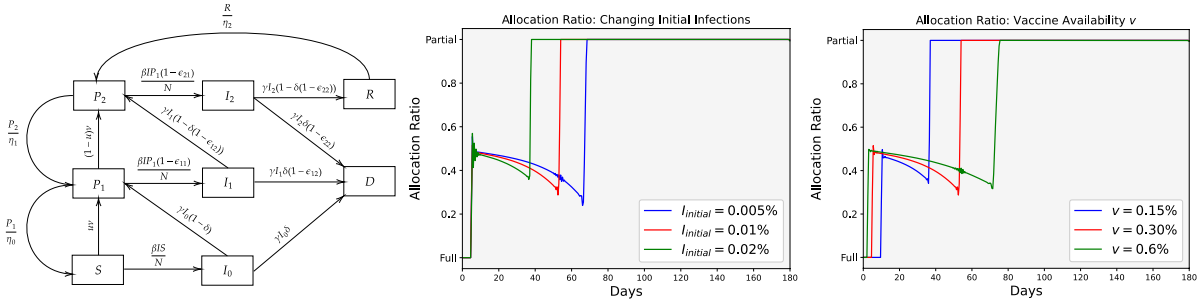
Introduction. Vaccinations have proven to be an effective intervention against infectious diseases. When administering a two-dose vaccine, an important point of consideration for the policymaker becomes the trade-off of partially vaccinating a large proportion of the population versus full vaccination of a smaller number (Matrajt, et al., 2021). This dilemma becomes even more pivotal when vaccine supplies are constrained. We identify an optimal allocation approach for the first and second vaccine doses by analysing the second wave of infections witnessed in the Indian state of Tamil Nadu. Subsequently, we offer actionable policy suggestions based on our findings.

Methodology. We developed an SIR model comprising three tiers: susceptibles, partially immunised and fully immunised. Transitions between these tiers are contingent upon allocating doses for partial or full vaccination. We use optimal control theory to obtain the optimal division of doses into partial or full vaccination. The objective function of the policymaker aims to minimise the costs resulting from deaths and vaccinations. Numerical analysis is done to assess the sensitivity of the allocation ratio for different factors like vaccine availability, first dose efficacy, active infections, and transmission rate.

Results. The numerical results provide an optimal profile of the allocation ratio over time. In the following figures, we contrast the baseline scenario (depicted in red) and assess the impact of two pivotal parameters within the model. In the baseline scenario, the optimal strategy involves complete vaccination for partially vaccinated individuals within the population. Following this, the optimal distribution profile recommends a nearly equitable allocation between the first and second vaccine doses shifting towards full vaccination with time. This shift extends further for low initial number of active cases or increased vaccine availability. Upon surpassing a threshold, a jump is observed, which leads to prioritisation of the first vaccine dose across all scenarios.



Conclusions. Optimal vaccination not only helps in preventing avoidable deaths but also in lowering the active number of infections in the population. Particularly in low- and middle-income countries (LMICs), where vaccine supplies are limited, the selection of an optimal strategy becomes critical. We look at the different scenarios that may be faced by the policymaker pertaining to the active number of cases, vaccine availability, first dose efficacy and transmission rates and provide policy recommendations. This research aims to enhance preparedness against potential future outbreaks of infectious diseases, whether they manifest as pandemics or endemics.

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Socio-demographic heterogeneity in cost of accessing medication abortion: insights from Ghana

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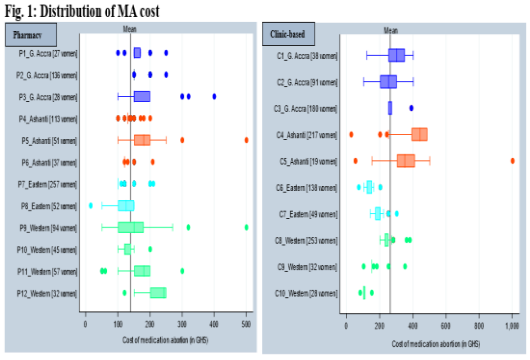
Introduction. Self-managing abortions with medication is predominant, especially in settings where abortion access is limited. Medication abortion (MA) is safe during the early stages of pregnancy (Kapp & Lohr 2020). In Ghana, abortion is permitted under certain liberal conditions in licensed health facilities (referred to as clinic-based) (Aniteye & Mayhew 2019). However, apart from the clinic-based facilities, MA services are covertly obtained in pharmacies to avoid abortion-related stigma. Previous studies have explored the impact of stigma on access to high-quality abortion care, but the disparities in the cost of accessing MA remain unknown. This study examined how women's socio-demographic attributes, along with the facilities providing MA, are associated with the cost of obtaining MA in Ghana.

Methodology. We used survey data from 1,974 women in Ghana who had MA with mifepristone and misoprostol combination pills obtained from clinic-based and pharmacy providers. The cost of MA is estimated based on the price women paid for MA pills and time spent at the facility to access MA. To understand the cost disparities both within and between facilities, an analysis of the variance was performed. Multivariate linear regressions were then utilized to examine how women's socio-demographic attributes contribute to variations in the cost of MA. Blinder-Oaxaca decomposition analysis (Jann 2008) was conducted to shed light on the mean difference in cost of obtaining MA between the two types of providers.

Fig. 1: Distribution of MA cost



Results. The average cost of MA varied between pharmacy (US$ 24.30) and clinic-based facilities (US$ 46.10). However, there were variations both between and within facilities in each group (Fig. 1). Among the clinic-based facilities, 78% of variation can be explained by between-facility differences, while for pharmacies, bigger share of variation, 57%, is driven by within-facility price differences. The regression results indicated that MA cost decreases with number of children and increases with education, after controlling for all possible observables and facility-level effects. About 69% of women with higher levels of education obtained MA from clinic-based facilities, where the cost is relatively higher. The decomposition analysis also suggests that there may be some price discrimination against clinic-based clients.

Conclusions. Our findings indicate that the cost of obtaining MA differs based on certain socio-demographic attributes of clients, the type of provider and the facility used. To reduce the disparities, it is important to develop strategies that limit service provider discretion, especially at the clinic-based facilities. One way is to formulate national guidelines on MA since its use has increased over time.

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Energy, Climate, and Environment (ECE)

Climate mitigation effects on poverty and household expenditure: consumption commodity heterogeneity in a global energy model

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Introduction. Ambitious climate policies are required to mitigate the expected severe damage of climate change that impact less-advantaged population the most. However, climate policies may themselves also affect the same populations adversely, for instance through higher food and energy prices, which make up large shares of expenditure in poorer countries. Current understanding of these policy side-effects around the world is lacking due to missing heterogeneity in household consumption in the integrated assessment models (IAMs) that are used to produce climate mitigation pathways. In this study, we fill this gap by simulating country-level effects of climate policies across 14 commodities for 10 deciles. Impacts on poverty and inequality are identified, through both price-expenditure and macro-economic income channels. This informs policy packages towards equitable climate change mitigation pathways at a higher level of detail than before.

Methodology. We simulate 1.5℃ and 2℃ scenarios in two IAMs: MESSAGEix and AIM/Hub. MESSAGEix has a more detailed energy supply system, while AIM/Hub has a more detailed representation of the economy. Regional outcomes from IAMs are downscaled to national level, and the national policy outcomes of poverty, domestic income inequality, and household consumption changes are assessed with lognormal income distribution and An Implicitly Directly Additive Demand System projections.

Results. Both models attribute additional poverty headcounts around the world to cost-effective climate mitigation policies, compared to a reference scenario without climate policy. Still, until mid-century this effect is about 91% smaller than the projected poverty alleviation from economic growth in same scenario. AIM/Hub projects stronger negative policy effects, mostly because MESSAGEix projects a lower income loss. Comparing between scenarios, more stringent climate policy generally led to the growing poverty headcount, except that MESSAGEix projected a smaller additional poverty headcount due to policy-induced price changes in 1.5℃ than in 2℃ scenario globally. In terms of inequality, AIM/Hub results show negative policy impacts on Gini coefficient globally in the whole simulation horizon, while the MESSAGEix results see countries with both inequality reduction and inequality increases. This is because prices for food and energy could increase or decrease by the policy in MESSAGEix.The results stated above are subject to change because there is still ongoing work on the scenario and policy design. Major uncertainties and limitations reside in the avoided impacts of climate change, the policy effects through employment channels, the combination of different mitigation measures and international financial corporation, etc.

Conclusions. Large variations in the potential poverty headcount and the associated sensitivity to climate policies across scenarios were revealed in our analysis. Both models confirmed that stringent climate policies, without effective countermeasures, would pose more challenges to poverty alleviation. But there are distinct distributional effects of climate policy at regional scales. The ambition to achieve the 1.5° temperature goal would pose significant challenges to income inequality abatement compared to the 2° goal. Overall, MESSAGEix projected a more optimistic future for poverty and inequality alleviation with climate policies in line with the Paris Agreement's temperature goals. We are using here a temperature-clustered scenario set to abstract the impacts and costs of climate change, but the avoided climate change impacts will be addressed in the next step.

Exploring more socio-politically credible coal and gas phase-out pathways

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Introduction. The committed emission of existing energy infrastructure is larger than the remaining carbon budget to limit warming from 1.5ºC (Tong et al. 2019). Social, political, and institutional factors play a crucial role in the Just Energy Transition (Cherp et al. 2018), especially in the move away from fossil fuels. This study builds on recent work (Cherp et al. 2018, Brutschin et al. 2021) that argues for a better understanding of the interaction of techno-economic and socio-political systems during transitions. We aim to understand how social, political, and institutional factors may influence the retirement of coal and gas power plants, their synergies, and the conversion to renewable energy infrastructure.

Methodology. Social, political, and institutional datasets in this study include global climate opinion surveys, availability of fuel and trade infrastructure, and power sector liberalization indicators. Plant-wise and country-level technology retirement calculations are based on open-source coal and gas tracker datasets from the Global Energy Monitor (GEM). These results are further analyzed through mixed methods, including regression analyses on datasets with more historical transition precedence and qualitative case studies on more novel transition pathways. We use LASSO and stepwise feature selection to inform the corresponding OLS models and predictor analysis. We also develop a multivariate random forest model for more robust future coal and gas phase-out projections.

Preliminary Results. Exploratory regression analysis on 1985-2021 country-level data suggested that social factors such as climate change worry are not correlated with the historical coal and gas phaseout. Political economy factors show weak linkages. For example, the shares of coal and gas in electricity are negatively correlated with coal phase-out (Fig. 1). Institutional factors, however, play a stronger role. Notably, the availability of consumer choice in the power sector is positively correlated with both coal retirement and phase-out. The existence of wholesale power markets is otherwise negatively correlated (Fig. 1).

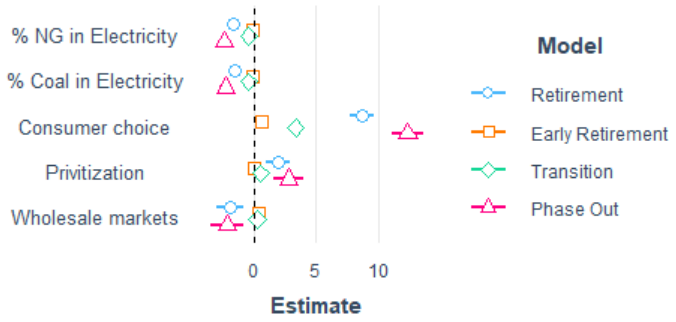

Fig. 1 Coefficient from exploratory linear regression models with coal dependent variables (i.e., retirement, early retirement, transition to natural gas, and phasing out peak capacity) and standardized independent variables.

Conclusions. Our work would inform more credible and equitable narratives of coal and gas phase-outs in climate mitigation scenarios in IAMs. We argue that improving existing assumptions in IAMs with insights from social and political sciences could address some of the feasibility and justice concerns that policymakers have recently raised. Such insights could also inform targeted policies and reforms to motivate more ambitious transitions.

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A comprehensive model for policy design and evaluation in the housing sector

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Introduction. The EU-28's building sector of the European Union (EU-28) was responsible for 40% of final energy consumption and 35% of emissions in 2019. Concurrently, approximately 34 million Europeans experienced challenges in home heating, highlighting the issue of energy poverty. While recent engineering models emphasize potential mitigation in building sectors of high-income countries, they often neglect market discrepancies and hidden costs in homeowners energy efficiency decisions (Gerarden et al., 2017). This study aims to identify policy frameworks that promote renovations and address energy poverty, by integrating a European household decision model with the building sector model MESSAGEix-Buildings (Mastrucci et al., 2021).

Methodology. Utilizing the latest European country-level data, we calibrated the global-scale MESSAGEix-Buildings model. We introduced a household energy behavior function for space heating energy consumption and an endogenous decision model for housing renovations and heating system upgrades. Our discrete choice models, addressing data challenges, were calibrated using results from discrete choice experiments and aggregated revealed data. We further examined energy-efficiency market inefficiencies, particularly the landlord-tenant dilemma and public good deficit in multi-family residences, using the household budget survey data.

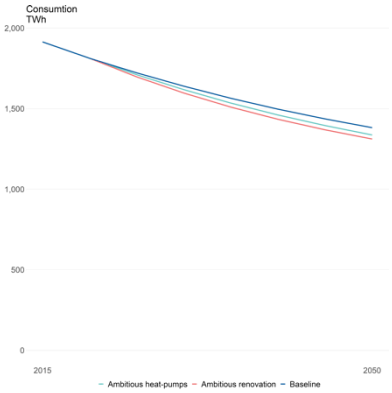

Figure 2: Simulation of space heating consumption for EU-28.

Results. We analysed two policy scenarios introducing ad valorem subsidies equivalent to 50% of the renovation and heat-pump installation costs respectively, assuming constant energy prices to focus on policy impacts. Figure 1 showed the reduction potential of the energy consumption under different policy scenarios. We then assessed cost and benefits of the policies over respective periods of 50 years for renovations and 20 years for heating systems (Figure 2) using a 3% social discount rate. Preliminary results showed renovation policies as largely beneficial, whereas heat-pump policies exhibited varied efficacy across member states and energy prices scenarios.

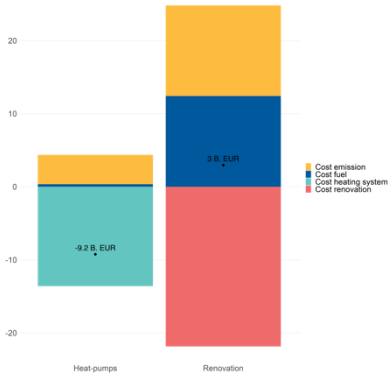

Figure 2: Cost-benefit analysis of renovation and heat-pump subsidies scenarios compare to the baseline. Benefits are discounted with a 3% social discount rate and assuming social cost of carbon of 100 EUR per ton of CO2.

Conclusions. In this study we have assessed different policy frameworks to underscore our methodology's capability to assess policy impacts at European, member state and household levels, a facet often overlooked in contemporary literature. Further research will provide insights into the distributive implications like energy poverty. Future endeavors will explore nuanced policy mix scenarios and varied carbon tax scenarios, offering actionable insights for policymakers.

Co-benefits of China reaching carbon neutrality: how they accelerate air quality improvement towards WHO Air Quality Guidelines

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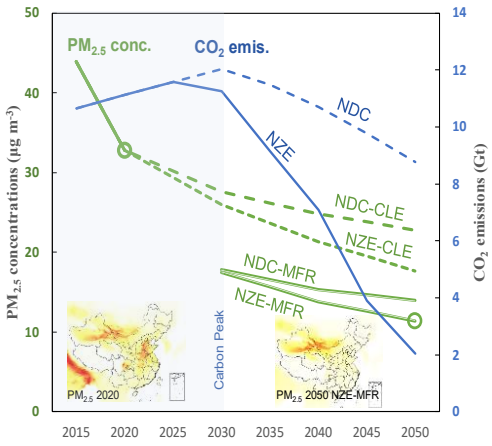
Introduction. China and many developing countries face simultaneous climate change and air pollution challenges. Actions to achieve carbon neutrality in China by 2060 would be essential for air quality improvement, however, may not enough for achieving the latest 2021 World Health Organization air quality guidelines (WHO AQG). Many integrated assessment models have estimated the mitigation pathways of CO_2 under different climate targets, and their co-benefits to reduce air pollutants. However, there are insufficient studies show clean air pathways at sub-national level, neither is the analysis of sectorial contributions.

Methodology. We coupled an integrated assessment model with China provincial details (GCAM-China) with Greenhouse Gas and Air Pollution Interactions and Synergies model (GAINS) to quantify the air quality improvement pathways. The energy activity data were mapped and imported into GAINS. We use GAINS for $PM_{2.5}$ concentrations and health impacts calculation. We set two carbon mitigation scenarios, Nationally Determined Contributions (NDC, follows Fawcett et al, 2015) and Net-zero carbon emission by 2060 (NZE), coupling with two air pollutant control scenarios, Current legislation (CLE) and Maximum feasible reduction (MFR).

Results. We find that 14 (out of 31) provinces of China can meet the WHO Interim Target-4 for $PM_{2.5}$ (i.e., annual average <10μg m^{-3}) by 2050 under NZE-MFR scenario, the most ambitious scenario. Guizhou, Hainan, Heilongjiang, Tibet approach or below WHO AQG (annual average $PM_{2.5}$ <5μg m^{-3}). This is attributed to large co-benefits of reductions in SO_2, NO_x, and primary $PM_{2.5}$ driven by decarbonization. The national population-weighted $PM_{2.5}$ concentrations decrease from 32.8μg m^{-3} in 2020 to 22.8 (NDC-CLE), 14.0 (NDC-MFR), 17.7 (NZE-CLE) and 11.4μg m^{-3} (NZE-MFR) in 2050. The remained premature deaths in 2050 will be 1.2, 1.0, 0.8 and 0.6 million, respectively. By 2050, natural source (dust) will dominate $PM_{2.5}$ concentrations of northwestern China, while industry will be the largest contributor in Northern and Eastern China.



Conclusions. We examine clean air pathways for China and the associated impact under the carbon neutrality goal towards WHO AQG. We find that carbon neutrality policy can reduce more than 80% of SO_2, NO_x, and primary $PM_{2.5}$ reductions, but still most of provinces cannot reach WHO IT-4 (10μg m^{-3}) by 2050, not to mention WHO AQG (5μg m^{-3}). Natural source contributes to around 4 μg m^{-3} nationally. The enhanced air pollution control (MFR) is crucial for further 35% $PM_{2.5}$ reduction and approaching WHO IT-4. The significant health benefits thus highlight the necessity of implementing additional air pollution control measures beyond those toward reaching carbon neutrality.

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South-South technology transfer: Barriers and enablers for a sustainable energy transition

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Introduction.

This project analyses South-South Technology Transfer for a sustainable energy transition. Technology transfer is key for decarbonisation, it plays an essential role in climate change negotiations as well as for mitigation and adaptation measures (Perrone 2022). The project investigates enablers of and barriers to successful technology transfer and problems generated by technology transfer. It examines which countries engage in technology transfer and in how far individual countries apply specific strategies related to certain types of technologies, highlighting inequalities between countries.

Methodology.

Data for the study was collected following the guidelines for systematic reviews of qualitative evidence (Cherry, et al., 2017). Databases searched include Scopus, Web of Science, Google Scholar, Semantic Scholar, OLC Internationale Beziehungen und Länderkunde, Research Papers in Economics / IDEAS, ProQuest Dissertation and Theses and Open Knowledge Maps. Google Scholar allows to access grey literature as well, furthermore, the search string for Google Scholar was translated into Spanish, French and Portuguese to cover diverse publication backgrounds. In total, 5037 entries were collected, after de-duplication the number of entries that formed the basis for the citation screening was reduced to 4822. 729 entries were selected for abstract screening.

Preliminary results.

While energy cooperation is being promoted broadly, institutional arrangements seem to facilitate collaboration more intensively than bilateral cooperation. In many cases, apart from climate agreements, foreign policy projects and investment are observed to determine technology transfer implementation and outcomes. A mapping of the results will outline common characteristics, show which regions are covered by research and demonstrate directions of technology transfer. Regarding the definition of the geographical scope of the study, how “South-South” is defined impacts the literature included in the review and thereby also influences the outcomes. To be able to select all relevant studies, an exploratory approach has been chosen to establish what science understands when using the concept of “South-South”, thereby identifying who defines the term and under which circumstances. Among the types of technology under examination – including sustainable and renewable energy as well as low carbon or energy efficiency technologies – hydropower appears to predominate due to specific technology transfer strategies.

Conclusions.

Identifying the enablers and barriers related to South-South Technology Transfer to broaden the use of low carbon and sustainable energy technologies facilitates a better understanding of how to fast-track and improve conditions for technology transfer. The results of this study could inform feasibility assessments of different mitigation pathways modelled for countries of the Global South or be useful in modelling energy transitions which assume certain technology uptake, and are relevant for policy as they point out where problems currently occur within the transfer of technology and how to increase the benefits of technology transfer for a transition to sustainable energy.

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Reducing food losses to improve sustainability in transformation pathways for the agri-food system in Sub-Saharan Africa – modelling impacts across the water, energy, food nexus

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Introduction. The agri-food system in Sub-Saharan Africa (SSA) predominantly relies on rainfed agriculture, exposing smallholder farmers to yield and income instability amidst already modest earnings[1]. Climate change exacerbates these issues through increased temperature and precipitation variations, putting local livelihoods at risk. Transformation pathways are urgently needed to make the whole agri-food system more sustainable and resilient, but their development is particularly challenging as also rapid socioeconomic changes are occurring. Concerted efforts by public and private stakeholders could encompass policy implementations and technological adoptions aimed at curbing agricultural, post-harvest, and processing losses, which together constitute over 75% of total wastage in the region[2]. Inefficiencies also extend to resource depletion (water, energy, land), with spillover effects via international food trade networks.

Methodology. To gain a Nexus perspective, different modelling tools are soft-linked. First, an input-output model (WASTE model) is used for quantifying food loss and waste within intricate trade networks[3], for 11 different crops and related food commodities. This model distinguishes five key stages of loss/waste, covering primary (e.g., wheat) and derived (e.g., flour, bread) products and it is able to reconstruct farm-to-fork supply chains. Feeding these outputs (together with other exogenous data) to IIASA's NEST model and the agro-hydrological WaterCrop model would allow us to: (i) map historical impacts of loss/waste on water, land and energy resources; (ii) assess future impacts of loss/waste on water, land and energy resources for a given scenario (SSP3-RCP7.0); (iii) evaluate impacts of future transformation pathways on Nexus resources.

Results. The first goal reached in the project is that outputs from WASTE model have been post-processed to become spatially distributed, to allow high-resolution mapping (about 10-by-10 km grid cells) of associated lost/wasted resources. Then, an empirical analysis allowed us to find statistically-relevant regressions between food loss/waste and socio-economic variables, and between energy use and food loss/waste, always distinguishing five different stages of food loss and waste. This let us have more accurate parametrizations of the WASTE model for future scenarios and provides a way to estimate energy use associated with food production in the current and future socio-economic conditions. NEST tool provides insights about the impacts on water and energy availability, in both present and future conditions.

Conclusions. Even though in present conditions food loss and waste in Sub-Saharan Africa (506 kcal/cap/day) is lower compared to other world regions (e.g., 1334 kcal/cap/day for North America), current trends in socio-economic conditions (e.g., increase in per-capita GDP and urbanization) would increase such figure. Increased impacts on water and land resources are therefore also projected. Within the food value chain, while supply-side losses are predicted to be reduced, consumption-side food waste on the other hand will increase, more than offsetting mentioned reductions upstream. Increased mechanization in agriculture, post-harvest and processing stages, which reduces loss rates, demands for higher specific energy inputs in food production. Sustainable transformation pathways might aim at further reducing losses and waste, but need to take into account trade-offs with energy security objectives.

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A spatially explicit study on the decarbonization pathway of China's iron and steel industry

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Introduction. The decarbonization of the iron and steel industry stands as a pivotal undertaking in the pursuit of global climate change objectives. While numerous previous studies have delved into potential decarbonization routes for the steel sector, a significant aspect has been regrettably overlooked: the regional divergence inherent in its transformation. Notably, disparate regions are characterized by unique environmental susceptibilities and diverse available resources, which have seldom been incorporated into present long-term integrated assessment models. Noteworthy in this context is China, acclaimed as the foremost global steel producer, and distinguished by its expansive territorial span. This study thus sets out to explore the decarbonization trajectory within China's iron and steel industry, considering a spectrum of demand and technological scenarios.

Methodology. The steel module of MESSAGEix-China model was employed to generate national-scale capacity trajectories across various scenarios. This model encompasses 22 process technologies within the iron and steel sector, spanning from resource extraction to intermediate material production and final product manufacturing. Utilizing national facility datasets, a machine learning approach called LASSO, and theoretical calculations, a comprehensive set of finely detailed metrics was formulated. These metrics enabled the simulation of the gradual replacement of outdated facilities and the establishment of novel ones. Several distinct scenarios were devised based on steel demand and potential technological advancements.

Results. An imperative arises within the iron and steel sector to promptly dismantle its high carbon intensity capacities, particularly those associated with blast furnaces (BF) and basic oxygen furnaces (BOF). A swift ascent is projected for the electric arc furnace (EAF) process, propelled by its utilization of scrap steel as the primary raw material. Concurrently, novel technologies like carbon capture, utilization, and storage (CCUS), along with hydrogen-based direct reduced iron (HDRI), are poised to assume pivotal roles post-2030, although they confront substantial uncertainties. The divergence of technological development scenarios may yield profoundly disparate industrial spatial arrangements. As depicted in the accompanying diagram, the HDRI scenario yields a more diffuse production capacity distribution across various provinces, in stark contrast to the CCUS scenario. The implementation of the HDRI scenario substantially mitigates the risk of water scarcity in the Hebei region, a phenomenon not replicated in the CCUS scenario. Nonetheless, akin to their relatively comparable distribution within the EAF (electric arc furnace) process, the distribution of electricity and scrap consumption remains analogous across the two scenarios.

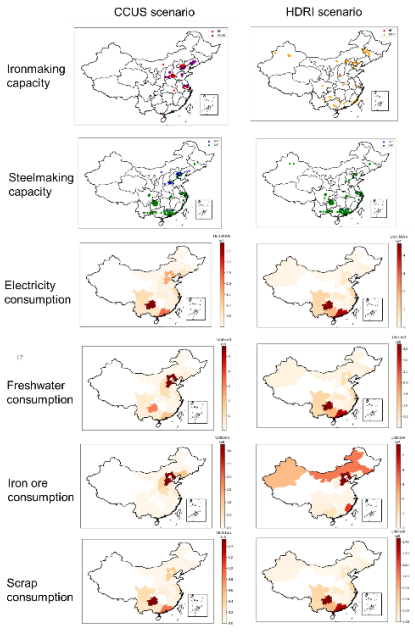

Figure. China's iron & Steel sector in 2050

Conclusions. It is imperative to meticulously examine the decarbonization pathway of China's iron and steel industry through the lens of intricate spatial detailing. The variances inherent in technological advancements might be magnified when scrutinized at a regional scale.

The net zero transition and role of energy trade in northeast Asia

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Introduction. The assessment of climate impacts and mitigation policies has primarily been conducted globally by splitting the world into a simplified regional group. Lately, researchers have raised the importance of analyzing climate change mitigation policies at a higher resolution spatiotemporal levels for different demand sectors. Northeast Asia (NEA) is a critically important region characterized by fast economic growth and a significant impact on global climate change. Yet, the amount of GHGs emissions attributed to energy trade in the NEA region has received much attention in the contemporary literature.

Methodology. The Model for Energy Supply Systems and their General Environmental impact (MESSAGE) is a mathematical model that describes a global energy system and centrally plans it for various GHGs reduction targets. This study uses the rapid prototyping Country Model Generator built by the IACC Research Group of the IIASA ECE Program to expand and calibrate a default 11-region global MESSAGE model into a 17-region global model by adding six countries in Northeast Asia. In addition to regional disaggregation, this study introduces configurations of inter-regional trade for three energy commodities: liquefied natural gas, pipeline gas, and electricity better to understand the trade dynamics in the NEA region.

Results. I find a significant difference in total LNG imports in the scenario assuming a remaining carbon budget of 1,000 GtCO2 by 2100 (Figure 1). These results stem from the rigidity related to LNG imports due to regional disaggregation, whereby the R11 model configuration provided an aggregated trade representation for dissimilar regions, e.g., for the Pacific Asia region (PAS), Korea is a net importer of LNG. At the same time, other countries are net exporter. With the R17 model configuration and a redeveloped LNG trade matrix, the analysis of dissimilar countries within a region becomes possible.

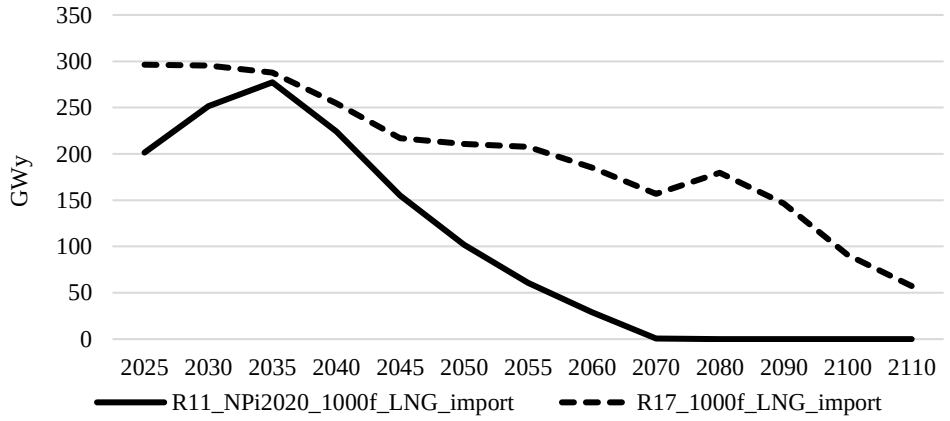

Figure 3 Total LNG import by model, R11 refers to the results of the original model, and R17 refers to the new model built in this study.

Conclusions. Through the implementation of regional disaggregation and the recalibration of energy trade, there is a different result in the carbon reduction scenario. The primary objective of this study is to conduct an in-depth analysis of regional disaggregation and energy trade, thereby investigating the impact of GHG reduction policy in a regional context. In the post-YSSP study, I will improve the model calibration and scenarios to provide analytical results with policy implications.

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Integrated diffusion modeling of bidirectional chargers, electric vehicles, and rooftop photovoltaics

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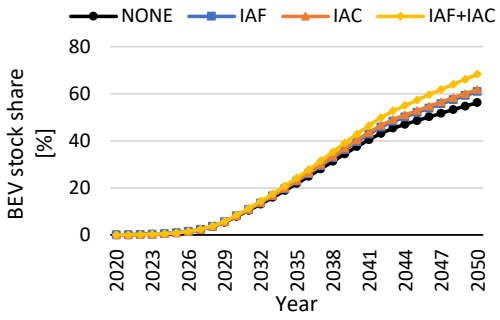
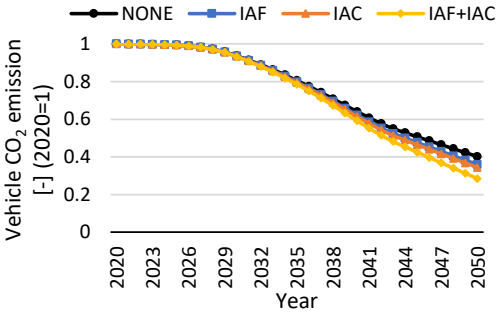
Introduction. This study focuses on the interaction between the diffusion of battery electric vehicles (BEVs) and their bidirectional home chargers called vehicle-to-home (V2H). In Japan, BEVs combined with V2H chargers are considered as promising flexibility resources for variable renewables in future power grids. Furthermore, additional revenues from bidirectional charging might encourage more vehicle users to adopt BEVs. Therefore, the objective of this study is (1) to develop a framework to model the collaborative diffusion strategy of BEVs & V2H chargers in Japan and (2) to examine whether and how V2H support policies can promote the diffusion of BEVs.

Methodology. In this study, a nested-logit discrete choice model was developed to calculate the market share of each vehicle type (ICEV or BEV) and BEV's home charger type (none, unidirectional home charger, or V2H charger). Its parameters were calibrated based on literature about Japanese consumers' BEV preferences (Yoshida, 2021) and the latest market sales data. Additional revenues by bidirectional charging, one of the explanatory variables, were calculated using a household energy system optimization model the author has already developed. Furthermore, users were categorized into six groups by access to home chargers, vehicle usage, and existence of rooftop photovoltaics.

Results. Using the developed model, we simulated the impact of two hypothetical V2H support policies on the BEV diffusion and resulting CO_2 mitigation of vehicles in Japan (Fig. 1); improved affordability policy (IAF; V2H purchase cost declines to same price as unidirectional chargers by 2050) and improved accessibility policy (IAC; home charger accessibility in apartment buildings increases from 0% to 100% by 2050). As shown in Fig. 1, both IAF and IAC policies could accelerate the adoption of BEVs. Especially, combining the two policies would increase BEVs stock shares by 12.1% and CO_2 mitigation by 11.8% in 2050 compared to those without either policy.



(a) Stock share of BEVs



(b) CO_2 emission of vehicles

Fig. 1. BEV diffusion and resulting CO_2 mitigation.

Conclusions. Our current results show that raising the affordability and acceptability of V2H chargers can accelerate the diffusion of BEVs and CO_2 reductions from vehicles. They imply that the co-benefits of V2H support policies should be considered for future BEV diffusion strategies. Further refinement of the developed model, input data and scenarios can improve the precision and reliability of the estimated policy impacts.

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Assessing the dynamics of technology adoption in lead and follower countries

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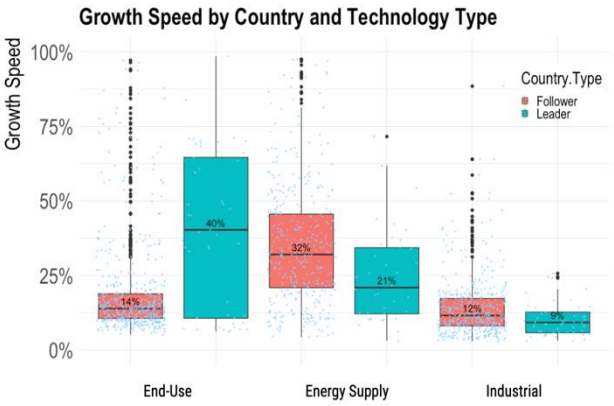
Introduction. Meeting global temperature targets will require rapid adoption of novel mitigation technologies. Understanding drivers of historical technological change and the differences in the speed of such change across countries can help inform plausible scenarios of future growth in novel technologies across countries. Particularly, understanding the conditions under which technologies grow quickly can inform the prioritization of resources toward novel technologies that share these traits. In this analysis, we combine historical technology adoption data from a diverse set of technologies with technology-specific characteristic data and country-level data on governance, political economy, and social indicators to better understand the underlying drivers of these cross-country differences in technology adoption.

Methodology. We use country-level data from the Historical Adoption of TeCHnologies (HATCH) dataset to measure the speed of technological diffusion (Nemet et al, in review). To determine technology diffusion speed, we fit a 3-parameter logistic function onto each country-technology dataset, using the steepness parameter to measure the growth speed of each country-technology pair. For each technology, we group countries into two groups: lead countries (where the technology was first commercialized or adopted soon after commercialization) and follower countries. We then apply multivariate linear and logit regression models across technology- and country-specific characteristics to assess the drivers of technological growth speeds across countries.

Results. We find that the speed of technological diffusion across countries where a technology is first adopted compared to later adopters depends on the technology type. For end-use technologies, the median growth speed in lead countries is faster (40%) than follower countries (14%), whereas the opposite holds for energy supply and industrial technologies; the median growth in follower countries grow is faster than lead countries (32% and 21%, 12% and 9%, respectively). Across 11 technology-level variables, the year of first commercialization, technological complexity, granularity, and technology category are the most significant indicators associated with growth speed. Across 13 country-level variables, the polity score, gross domestic product per capita, and country type (lead or follower) are most significantly associated with growth speed.



Conclusions. As governments take steps toward mitigating climate change, understanding the drivers of fast historical technological growth can inform resource allocation toward those that may diffuse faster. This analysis particularly highlights past technological change in which technologies disperse and scale-up quickly across countries. Prioritizing resources on technologies that may grow quickly in late-adopting countries can facilitate technology transfers under the Paris Agreement. Our preliminary results indicate that not all climate-relevant technologies may grow similarly to one another and that country-level factors should be considered when modelling future technological change. Future work can explore the addition of different regional growth dynamics in Integrated Assessment Models for novel mitigation technologies.

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Enhancing the representation of variable renewable energy in integrated assessment models: Softlinking PyPSA-Eur and MESSAGEix-GLOBIOM

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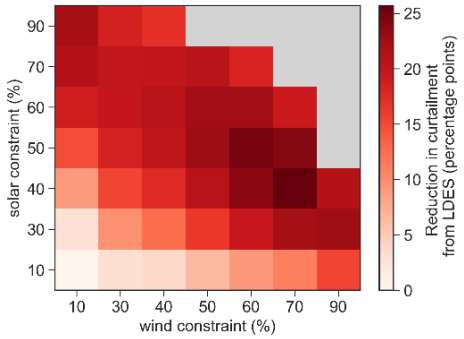
Introduction. Integrated Assessment Models (IAMs) serve as important tools for investigating coupled global dynamics encompassing climate, environment, energy, economy, and human health. Given their broad scope, they commonly adopt annual snapshots and vast continental-scale spatial domains. This level of resolution holds notable implications for the power system representation. First, it neglects the temporal alignment between energy supply and demand. Second, the spatiotemporal variability of wind and solar is not resolved in the modelling of variable renewable energy (VRE). Third, it does not model the flow of electricity through cross-border transmission lines. Consequently, IAMs often need to emulate these phenomena with sets of equations and parameters. Here, we extent the space of parameters to obtain a more realistic behaviour of VRE in IAMs.

Methodology. The scenarios are modelled and derived in the high-resolution sector-coupled power system model PyPSA-Eur. They are defined by their wind-solar ratio and total VRE penetration level. Each VRE combination is assessed for the impact of specific VRE integration support measures. To incorporate this impact into the parameterization of VRE in the IAM MESSAGEix-GLOBIOM, we refer to the four established equations that delineate the VRE integration in the model [1,2]: 1) renewable curtailment, 2) firm generation capacity requirement, 3) flexibility needs, and 4) additional integration costs. As an illustrative instance, we focus on the scenario involving the activation of long-duration electricity storage (LDES).



Preliminary results. Through a comparative analysis of curtailment curves in both models, we show that the baseline of MESSAGEix-GLOBIOM is aligned with the obtained curve from PyPSA-Eur under two circumstances: 1) in regions where wind or solar predominates, thus disregarding wind-solar interference, and 2) when VRE support remains absent. Presently, the parameters associated with storage in MESSAGEix-GLOBIOM fail to adequately encompass the influence of wind-solar interactions and the implementation of LDES.

Conclusions. The preliminary results address the necessity of an extension of the existing library to achieve a more comprehensive representation of VRE, encompassing a broader spectrum of conditions. For this reason, the next steps involve defining new relations in MESSAGEix-GLOBIOM that represent the solar-wind ratios and the inclusion of LDES. Subsequently, we will follow the same workflow to include the effect of other VRE integration supports.

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Evidence-based scenarios for Global South passenger mobility in large-scale IAMs: A case study for South Asian countries

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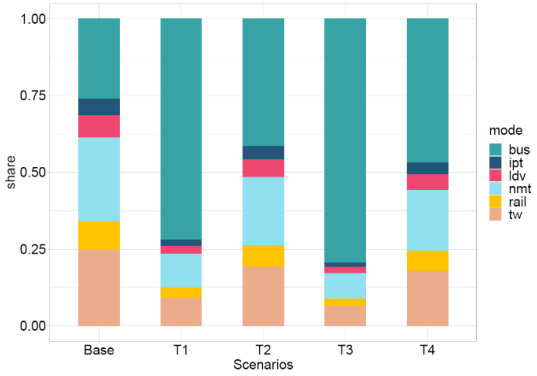
Introduction. Integrated Assessment Models (IAMs) are integral to informing climate change mitigation policies. However, these models have been critiqued for their techno-economic nature and limited representation of demand-side mitigation options. The exogenous parameters of these models generally do not include direct measures of many socio-cultural, behavioural, and lifestyle phenomena. Further, the introduction of new transformations in modelled scenarios lacks underpinning empirical evidence. Most of the narratives underlying these scenarios assume that certain causal relationships identified in specific part of the world—often, high-income countries—will have similar impacts across all regions. A detailed analysis of future transport needs for Global South countries is missing and requires greater attention given the expected increase in mobility demand owing to population and economic growth. The intended contribution of this work is to improve the quantification of sustainable mobility scenarios in IAMs for the Global South, with a focus on the South Asian region.

Methodology. We conduct a literature review to understand the causal relationship between various phenomena (such as urbanisation, national policies, environmental awareness, etc.) and passenger mobility. Each of these phenomena are mapped to exogenous parameters of MESSAGEix-Transport and calibrated from existing literature, prioritising evidence from South Asia and then Global South. The exogenous parameters include passenger distance travelled (PDT), its share across modes, and the ownership, occupancy, and technology shares of private cars. We utilize rich transport data (Indian Census 2011) to develop and calibrate our model of passenger mobility demand for the whole of South Asia considering the differences between other countries and India. The base model projections are driven by country-resolution growth in population and economy. For each scenario, a set of interacting phenomena produce new sets of PDT by mode, that are then inputs to MESSAGEix-Transport.

Results. Figure 1 shows the change in mode shares across scenarios for a "city" in India in 2050. As compared to the "Base", there is a shift towards public transport in all scenarios., with greatest change in T1 & T3. RH in T2 leads to greater share of LDV and a shift away from public transport.

Scenario	Phenomena
T1	PTI, TOD
T2	RH, PTI, TOD
T3	URB, RH, PTI, TOD
T4	PTI, ELF

Where: **PTI**- Public transport infrastructure; **RH**- Ride hailing; **TOD**- Transit oriented development; **URB**- Urbanisation; **ELF**- E-life (work-from-home, Tele-X)



Conclusions. The passenger transport mobility scenarios developed herein are based on evidence and data specifically from South Asian countries, thereby aligning with actual potential mitigation in this region. This method avoids biases arising from modelling methods and calibrations grounded in evidence and observed phenomena (e.g., LDV motorization) from the Global North. The demand model developed in this project produces IAM parameters with the dimensions of area type (large city, city, town, rural); trip distance; trip share; mode share; and trip rate, according to outcomes for several phenomena in each scenario. The relative richness of this model improves on top-down calculations often employed to quantify IAM scenarios such as [1].

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Pathways to inform the equitable implementation of the Paris Agreement

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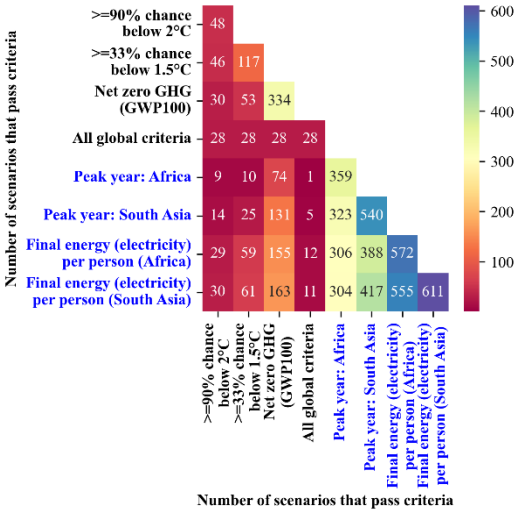
Introduction. The Paris Agreement represents a paradigm shift in efforts to mobilise a global response to tackle climate change. It enshrines a global commitment to hold warming "well below 2°C", "pursue efforts to limit warming to 1.5°C", and to do so based on "equity and common but differentiated responsibilities"[1]. Here, we propose a conceptual framework to operationalise equity in a new generation of mitigation pathways. This conceptual framework departs from existing equity frameworks in the literature in two ways: (1) it does not assume substitutability between different principled considerations, and (2) it focusses on quantities beyond emissions.

Methodology. Our conceptual framework maps principled considerations to variables reported by Integrated Assessment Models (IAMs) and then orders them along two dimensions. The first dimension indicates whether a criterion is a "mandatory criterion" or a candidate for "systematic investigation". Mandatory criteria are those that lend themselves to a ceiling (do not exceed) or floor (do not fall below) formulation. Criteria where reasonable disagreement exists on the desirable thresholds (e.g., regional carbon budgets) fall into our "systematic investigation" group. The second dimension groups criteria according to their regional applicability. As a first step, we apply a subset of the mandatory criteria to evaluate the scenarios assessed in the IPCC's 6th Assessment Report (AR6)[2]. We display illustrative results for two aggregate regions (South Asia and Africa) below. Building on this work, we develop a diagnostic scenario protocol for the MESSAGEix-GLOBIOM IAM to provide a model-specific translation of the criteria we propose.

Preliminary results. We compare the regional results from the AR6 scenario database with a selection of global (black labels) and developing region (blue labels) criteria in Figure 1. Only 28 scenarios that also report regional data among those assessed pass global criteria suggested by ref.[3] that can be mapped to the long-term temperature goal of the Paris Agreement (Article 2.1) and the mitigation objective (Article 4.1). Of these, only one scenario has a peak emission year for Africa that is after the global peak year (regional differentiation consistent with Article 4.1), and only 12 scenarios from this set do not see a reduction in final energy from electricity per person for this region (to meet one interpretation of Sustainable Development, as contained in Article 2.1(b)).



Conclusions and next steps. We are currently implementing the diagnostic scenario protocol in MESSAGEix-GLOBIOM. The results from these diagnostic scenarios will help us in two ways: (1) to assess trade-offs and synergies resulting from this systematic modification of criteria relevant to equity, and (2) to expand the solution space to enable wider stakeholder consultation on possible futures. Beyond evaluation of a single modelling framework, this protocol can be implemented in multiple IAMs in a Model Intercomparison Project (MIP) to investigate robustness of the trade-offs and synergies between different principled considerations relevant to equity under the Paris Agreement.

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Modelling scenarios for chemical production and consumption under China's circular economy and climate goals

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Introduction. China has the most comprehensive and large-scale chemical sector in the world, accounting for nearly half of the global chemical sector's energy consumption and carbon emissions. A model-assisted scenarios analysis will be important to guide the low-carbon and circular transition of the hard-to-abate sector. This study has the objective of extending socioeconomic shared pathways (SSPs) for the chemicals sector in China, considering both the supply and demand aspects. It will explore the transition of chemicals industry in China under different SSPs to provide insights on further circular economy policies and technology development.

Methodology. This study consists of three steps. Firstly, design the narratives for the supply and demand of primary chemicals in China under five SSP baseline scenarios. This includes composing qualitative texts illustrating the logic of each SSP and extending it to assumption matrices. Secondly, quantify the assumptions into input parameters under SSP1-3. For the supply side, project the cost of technologies using learning rate and GDP growth. For the demand side, break down and then aggregate the historic demand data of chemical products to calculate the elasticity of primary chemical consumption. Thirdly, implement the scenarios using MESSAGEix-Materials model.

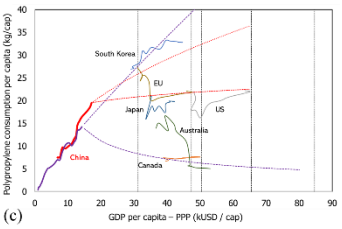
Results. Figure (a)(b) shows the qualitative assumption matrices of the supply and demand of primary chemicals in China under five SSP baseline scenarios. It refers to the common assumptions of fossil energy supply and energy conversion technologies across SSPs while considering China's actual situations. Figure (c) shows the break-down and aggregate of chemical demand projections under different elasticities. The scenarios are being implemented in the MESSAGEix-Materials model right now and results will be represented in the final report.

(a)

Supply side	SSP1	SSP2	SSP3	SSP4	SSP5
Fossil fuel supply					
Coal	restrict	medium	support	support	support
Oil & Gas	medium	support	restrict	medium	support
Trade barrier	no	some	high	some	no
Alternative technologies development					
Biomass conversion	high	medium	low	high	low
CCU + Hydrogen	high	medium	medium	high	high
Energy intensity	low	medium	high	low	medium

(b)

Demand side	SSP1	SSP2	SSP3	SSP4	SSP5
Population	fast decrease	med decrease	reach platform	fast decrease	fast decrease
Economic growth	medium	medium	slow	slow	rapid
Chemical demand per capita					
Circular economy strategies					
Reduce	high	medium	low	low	low
Reuse	high	medium	medium	medium	low
Recycle	high	medium	medium	high	high
Land use					
Land use regulation	strong	medium	weak	medium	medium
Land productivity growth	rapid	medium	slow	medium	rapid



(c)

Conclusions. Extending the global SSPs to specific sector and region and exploring the application of scenarios in MESSAGEix -Materials module may provide references and/or directly contribute to IIASA's CircEUlar project, to understand the dynamics and levers for societal and technological transformation towards a net-zero emission circular economy specifically the role of the chemical industry as well as the details of material cycles.

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Towards an integrated assessment of electro-microbial protein production from CO_2 and H_2

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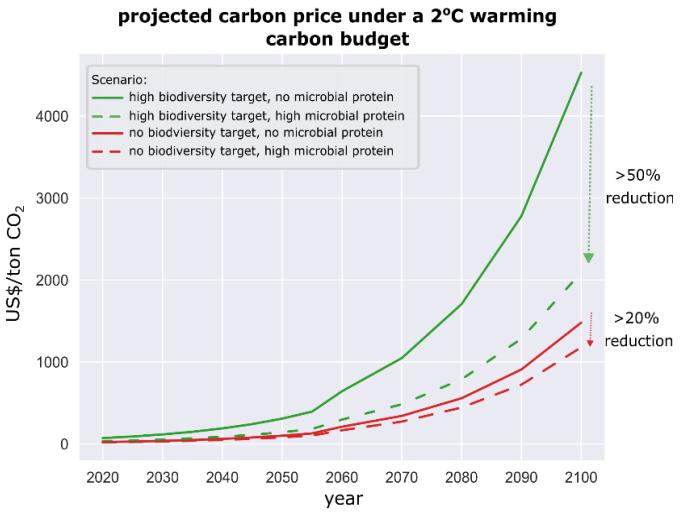
Introduction. Climate change, pollution, and biodiversity decline are interconnected crises heavily influenced by vital industries producing our necessities. Implementing sustainable and economically viable alternatives on a large scale presents a significant forthcoming challenge. For instance, plant-derived biofuels, once promising, face limitations due to competition with food crops. An emerging solution gaining traction is electro-microbial production, utilizing CO_2 and additional chemical feedstocks such as hydrogen or methanol to cultivate microbial biomass. This biomass serves as a platform for vital commodity production while potentially reducing its environmental foot-print, by avoiding competition for resources like land and water. We seek to analyze the economic and environmental facets of hydrogen and CO_2-based microbial production. This assessment will compare scenarios with and without microbial protein as a replacement for beef and offer insights into its potential for fulfilling environmental and climate policy objectives.

Methodology. We use a novel model combination of two independent linear optimization models to simulate the potential implications of electro-microbial protein production across multiple sectors. The first tool, MAgPIE developed at the PIK, assessed the implications for land use and agriculture. The second tool, MESSAGEix from the IIASA, modeled the effects on the energy system. By linking these we achieved a comprehensive evaluation of the potential impacts. To inform MESSAGEix on the energy and resource requirements for electro-microbial protein production, a literature review was conducted, these values alongside MAgPIE scenarios served as input for the new technology and land emulator in MESSAGEix, respectively.

Preliminary Results. Preliminary results include four scenarios: combining either high/no microbial protein replacement of beef with high/no biodiversity targets. When running the linked models under a carbon budget constraint of 600Gt by the end of the century (which corresponds to 1.5ºC warming), notably one scenario resulted in infeasibility - no microbial protein and high biodiversity targets. Suggesting that achieving both biodiversity and climate goals requires a change in the current agricultural system which could be resolved by the substitution of beef with microbial protein. When we adapted the constraint on our model by introducing a 1,000Gt end of the century budget (corresponding to 2ºC warming), all scenarios were feasible, yet implementation of microbial protein on a certain biodiversity target resulted in substantial reduction in the carbon price required to achieve the climate goal (figure).



Conclusions. Electro-microbial production of protein is an effective strategy in achieving climate targets via lower carbon prices, decreasing carbon cost ≈2-fold lower compared to the relevant no replacement base case. When stringent biodiversity and climate targets were set, microbial protein has been shown to be indispensable in-order to achieve the 1.5ºC degrees warming target which was found infeasible by the model in the absence of microbial protein.

Techno-economic-environmental assessment of phosphorus recovery from sewage sludge: Challenges and requirements

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Introduction. Phosphorus (P) is a crucial mineral for life and food. Limited, unevenly distributed phosphate rock drives P recovery from sewage sludge, ensuring sustainability, enhancing circular economy, and improving food security. Ideal approach in P recovery should consider high recovery, economic feasibility, and product with low environmental impacts and high agronomic value tailored to local conditions (Amann et al., 2018). We investigate different scenarios of the P recovery from P-rich streams (supernatant, sludge, and ash) in wastewater treatment plants (WWTPs) in Sweden, considering the commercially available technologies and current market characteristics.

Methodology. We categorized Swedish WWTPs by population coverage using Eurostat data (Eurostat, 2022) and estimated the P content in sludge, supernatant, and ash. Data related to P recovery technologies and their environmental impacts are sourced from the literature. We calculated P recovery cost in all WWTPs when recovery technologies were added to the existing plants. The cost includes investment, energy and chemical demands, annual fixed costs, and revenue from added technology. The optimal technology is selected based on the lowest P recovery cost, while the environmental impacts, such as global warming and acidification potential, are calculated for each WWTPs. We also explored establishing WWTP hubs within a 100-kilometer radius of WWTPs with capacities of more than 100k population equivalent (p.e.) to enhance economic viability through economy-of-scale benefits.

Results. Economic feasibility of P recovery via investment in recovery technology is contingent on investment, chemical, and fertilizer prices. The most economical option is found in larger plants, yet the gap between sludge-based fertilizer and commercial one is significant. Figure 1 shows the results for sewage sludge across WWTPs categories. Technologies display a wide range of environmental impacts. P recovery from sludge ash mitigates concerns regarding contaminants, heavy metals, and efficiency of sludge-based fertilizer. Revenue from P recovery is insignificant due to low amount of phosphorus and low market price of fertilizer. The hub establishment between proximate WWTPs to treat sludge and recover P shows economic benefits and lower price for P recovery. This can be attributed to economies of scale and gate fee revenue that a hub receives by accepting external sludge.

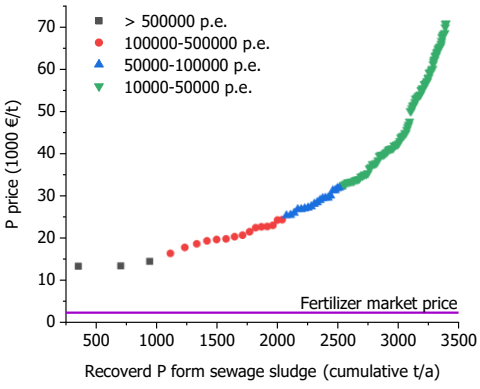

Figure 1- P recovery costs in Swedish WWTPs

Conclusions. The dominance of numerous small-scale WWTPs causes logistical and economic hurdles for P recovery. New investment in WWTPs becomes viable when sludge management costs are reduced and sludge is converted into marketable products such as char. The need for collaborative sludge management and legislative support is vital in P recovery from WWTPs.

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Assessment of carbon footprint of Ghana's charcoal value chain: the case of Kintampo Forest District

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Introduction. About 1.1 million tonnes of charcoal are produced annually in Ghana and this is projected to increase over the next years. Nevertheless, concerns about the impact of charcoal production and consumption on climate-altering emissions, continue to rise in Ghana. This calls for empirical studies to understand the impact of the charcoal industry on climate change. Few empirical studies investigating the charcoal sector in Ghana exist, but these have mainly focused on the production stage. Therefore, our study seeks to address this gap by assessing the carbon footprint of the charcoal value chain, using the Kintampo Forest District in Ghana as a case study.

Methodology. We employed a quantitative research approach using time series data on charcoal production and consumption at a sub-national level (Kintampo Forest District) in Ghana from the year 2016 to 2022 to understand the spatiotemporal pattern of charcoal production and consumption as well as greenhouse gas (GHGs) and short-lived climate pollutants (SLCP) emissions associated with the charcoal value chain (production, transportation, and consumption). We conducted a time series analysis using descriptive statistics to understand how charcoal production and consumption have changed both in time and space over the seven years. We then quantified GHGs and SLCP emissions along the charcoal value chain using the IPCC 2006 guidelines (Tier I) approach.

Results. We found that over the seven years, 2019 recorded the highest value of charcoal produced (39.5 kilotonnes [kt] while 2016 recorded the least (28.6kt). From 2016 to 2022, the average annual value of charcoal production in the Kintampo Forest District was 34.3kt. This is about 14.3% to 22.1% of the national average annual charcoal production in Ghana. The average monthly value of charcoal production and consumption ranged from 2.4kt to 3.3kt. Accra and Kumasi were the major destination points for charcoal produced in the Kintampo north and south districts with average annual values of 21kt and 10.5kt respectively. We found that annual GHGs and SLCP emissions from the entire charcoal value chain ranged from 223.9 kilotonnes of carbon dioxide equivalence [ktCO_2e] to 309.1ktCO_2e. The highest emissions of GHGs and SLCP within the charcoal value chain occur during the production stage (119.3ktCO_2e to 164.7tCO_2e per year). The least quantity of GHGs and SLCP emissions were recorded at the transportation stage with an annual emission range of 2ktCO_2e to 3ktCO_2e.

Conclusions. The charcoal value chain constitutes a significant source of GHGs and SLCP. Our findings demonstrate a perfect positive correlation between the quantity of GHGs and SLCP emissions and charcoal production and consumption. Therefore, there is a possibility of a further increase in GHGs emissions if the production, transportation, and combustion of charcoal continue on a business-as-usual trajectory. We propose both a more climate-smart charcoal value chain that focuses on sustainable harvesting of biomass and efficiency along the value chain and a transition away from charcoal to less polluting cooking fuels. Such a transition would need to be just and ensure that those involved in jobs along the charcoal value chain can engage in alternative livelihoods.

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Biodiversity and Natural Resources (BNR)

Attribution of historical river streamflow deviations to direct and indirect anthropogenic drivers

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Introduction. Recent global studies have shown that river streamflow has deviated far beyond stable, undisturbed conditions, and this change is driven by a mix of direct and indirect anthropogenic forcing. Climate change and variability alter the quantity and timing of precipitation, land surface routing of precipitation to streamflow is modified and interrupted by land cover change, and water may be withdrawn from freshwater bodies for human use. However, few global studies have estimated the different contributions of these key drivers, and they often resort to mechanistic hydrological modelling. This isolates the interdependent human drivers from each other and allows only for incorporating mechanisms that are implemented in the hydrological models. Therefore, we propose that the relationship between human drivers and streamflow change should be investigated in a more direct way.

Methodology. We queried the GSIM and Caravan databases to yield ~12,000 catchments with more than 30 years of consecutive streamflow observations. Human drivers (n = 17) were derived using zonal means or sums from ERA5-Land (climate), LUH2h (land cover), and Huang et al. (2018) (water use). To prepare streamflow and driver signals, we related monthly values with the mean monthly value of 1971–2000 (making the signals area-invariant) and applied a five-year rolling mean over the signals (smoothing over extremes). Then, we grouped the catchments by dominant climate zone and land cover type (n_{groups} = 18). We trained an XGBoost machine learning model in each group between the rolling mean streamflow signal and rolling mean driver signals. Within groups, the models were validated in unseen space, i.e. in catchments not overlapping with the training data set, and in unseen past and future time, i.e. in training data catchments but in the beginning and end of the time series for each catchment.

Results. The regional XGBoost models show low to moderate performance: median R2 ranges between 0.42–0.80 (mean 0.68) in all catchments within-group, 0.27–0.75 (mean 0.55) in unseen space and 0.20–0.65 (mean 0.50) in unseen time. In 12 out of 18 groups, unseen catchments are predicted better than unseen time – meaning that the models regionalise better in space than in time. The mean streamflow signal is reproduced well (R2 > 0.7) in 68% of all catchments by at least one of the 18 models. Combining the feature importance of the best-performing model and significant trends in drivers, we suggest that the leading driver of significant streamflow change is climate in 42% of the catchments, land cover change in 46% of the catchments, and water use in 12% of the catchments.

Conclusions. Here, we have shown that it is possible – with moderate but varying performance – to reproduce observed mean streamflow patterns using a set of 17 human drivers at the global scale. The performance of our XGBoost models is a trade-off between accuracy and generality, though we show that the mean streamflow signal can be adequately reproduced in most of the catchments by at least one of our 18 regional models. The work should continue with a more in-depth investigation into the most important features within each model and catchment, as well as with a CWatM- and similarity-based regionalisation to ungauged catchments to achieve full global coverage.

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Demand-driven climate change mitigation of the Swedish forest sector from a system's perspective

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Introduction. The forest sector contributes to climate change mitigation by sequestering carbon in forests and storing it in wood products. By consuming wood products, emission-intensive fossil materials or energy sources are avoided, resulting in a substitution effect. The Swedish forest sector is among the largest in the European Union in terms of the production of wood products and national harvest volumes. National carbon sequestration in forests and storage in wood products has been quantified for several years and is part of official LULUCF sector reporting to the UNFCCC. However, there is insufficient knowledge concerning the size of the Swedish forest sector's substitution effect based on wood product demand within and outside Sweden to estimate the entire Swedish forest sector's climate effect.

Methodology. To assess the demand-driven substitution effects and carbon balances of forests and wood products for the entire Swedish forest sector, this study integrates official national wood harvest scenarios from the Swedish forest decision support system Heureka with demand from the global GLOBIOM-forest model and a wood flow and life cycle assessment model. The harvest scenarios include a "Business-as-usual", "Biodiversity", and "Growth" scenario, representing three developments of future harvest and corresponding forest carbon stock developments. The harvest volumes of the scenarios were linked with domestic Swedish and international wood product demand derived from GLOBIOM-forest. The demanded quantities of wood products within Sweden as well as abroad were subsequently assessed as to their biogenic carbon storage, as well as their substitution effects applying half-life times and life cycle inventory data, respectively, to quantify the demand-driven climate change mitigation potentials of the Swedish forest sector from a system's perspective.

Results & Conclusions. Our assessment shows that the largest climate change mitigation from 2020-2010, including domestic consumption as well as exports, is reached under continuation of current forestry practices ("Business-as-usual"), amounting to about -69 Mt CO_2 eq $year^{-1}$. However, in the short-term, i.e., from 2020-2050, a decreased harvest intensity ("Biodiversity scenario") yields the strongest mitigation effect with -85 Mt CO_2 eq $year^{-1}$. Across the scenarios, forest carbon stocks contribute mostly to the overall sink while domestic and substitution abroad together can hold a comparable climate mitigation benefit. In the short-term, substitution from exported wood products is greater than that from domestic consumption, yet over time substitution effects from exports decline over time, and those of domestic consumption increase, except in the "Growth" scenario. We conclude that a substantial part of the Swedish forests sector's climate balance lies outside Sweden which must be considered when assessing the total sector's climate change mitigation potential.

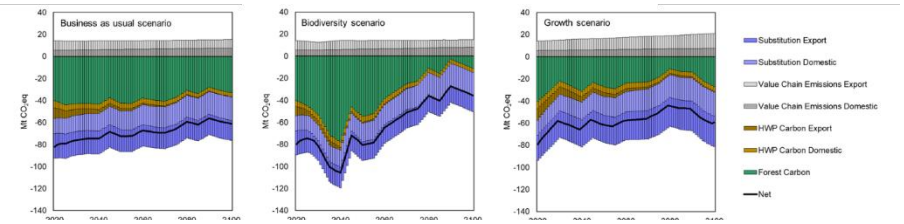

Figure GHG balance of the Swedish forest sector including forest carbon, and wood product demand within Sweden as well as from exports abroad.

Studying the impact of agricultural subsidies across Europe using a Bayesian spatio-temporal clustering model

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Introduction. The global climate crisis has conceived the need for impactful policies improving environmental sustainability across all sources, including agricultural goals like the promotion of organic farming and the management of pesticides and fertilizers. In order to study the effectiveness of mitigation policies, statistical methods need to consider complex bio-physical and socio-economic processes. To this end we combine data on different farm subsidies with land use data, economic variables as well as biophysical data like aspect and slope of the areal unit in question. We propose a Bayesian spatio-temporal model for exploring the impact of agricultural subsidies on land usage while simultaneously controlling for other relevant drivers.

Methodology. In order to infer the impact of the covariates of interest on the different land-use categories, we employ a Bayesian multinomial logit model. Furthermore, we combine the model with a non-parametric prior in order to cluster areas which exhibit similar results of the policy in question. To disentangle the effects of the policy and the remaining predictors, we split the likelihood and apply the clustering mechanism solely to covariates related to farm subsidies.

Results. Using the aforementioned algorithm, we obtain posterior samples of the regression coefficients as well as the clustering indicators. We find a point estimate for the latter by minimizing the binder loss function. The point estimate is shown in Figure 1, whereby each of the 978 considered NUTS 3 regions is coloured based on its cluster assignment. In total 11 clusters were estimated, out of which 3 entail the majority of all areal units. Table 1 shows the covariates used in the analysis and Table 2 the number of NUTS 3 regions per country included in every cluster. The posterior estimates of the regression coefficients are not reported to avoid misinterpretation of the results, which are preliminary at this stage and need further and careful examination.

Economic variables
Employment in the primary sector
Employment in the tertiary sector
GDP per capita
Population density
Biophysical variables
Aspect
Elevation
Slope
Variables related to farm subsidies
Farm output per ha
Farm rent per ha
Farm subsidies on crops per ha
Farm subsidies on livestock per ha
Decoupled payments per ha
Environmental subsidies per ha
LFA subsidies per ha
Total support for rural development per ha

Table 1: Covariates included in the analysis.

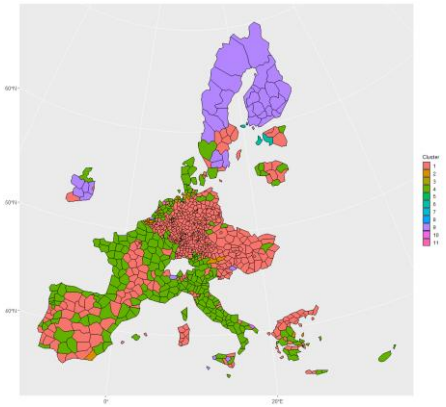

Figure 4: Estimated clustering based on the impact of farm related covariates.

Country	1	2	3	4	5	6	7	8	9	10	11
AT	25	2	1	7	0	0	0	0	0	0	0
BE	29	11	1	3	0	0	0	0	0	0	0
CY	0	0	0	1	0	0	0	0	0	0	0
CZ	12	0	0	2	0	0	0	0	0	0	0
DE	336	8	8	48	1	0	0	0	0	0	0
DK	3	0	0	8	0	0	0	0	0	0	0
EE	3	0	0	1	0	1	0	0	0	0	0
EL	29	3	0	13	0	0	1	1	0	0	0
ES	22	1	0	27	0	0	0	0	0	0	0
FI	0	0	0	0	0	1	0	0	18	0	0
FR	34	0	0	61	0	0	1	0	0	0	0
HU	19	0	0	1	0	0	0	0	0	0	0
IE	2	0	0	1	0	0	0	0	5	0	0
IT	28	0	0	78	0	0	0	0	3	1	0
LT	5	0	0	5	0	0	0	0	0	0	0
LU	0	0	0	1	0	0	0	0	0	0	0
MT	0	0	0	2	0	0	0	0	0	0	0
NL	6	0	5	25	0	0	0	0	2	0	2
PT	12	0	0	11	0	0	0	0	0	0	0
SE	9	0	0	2	0	0	0	0	10	0	0
SI	11	0	0	0	0	0	0	0	1	0	0
SK	8	0	0	0	0	0	0	0	0	0	0

Table 2: Number of NUTS3 regions per country and cluster.

Conclusions. We introduce a novel Bayesian multinomial logit model for the analysis of spatio-temporal data involving a nonparametric prior enabling clustering of the data based on the estimated covariate effect. The model's specification allows to separate covariates into those which influence the clustering and those which do not but are still controlled for. To obtain samples from the desired posterior we develop a suitable Markov chain Monte Carlo (MCMC) algorithm using recent developments in the literature. Our results indicate heterogenous effects of farm subsidies across the considered NUTS 3 regions.

Data-driven modeling of fires in a megadiverse country

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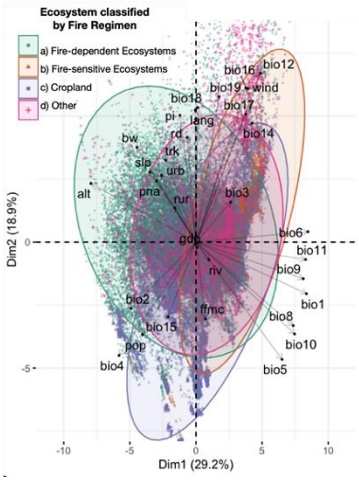
Introduction. Mexico has a large range of climates, and consequently, a megadiverse flora, including widely dissimilar types of forests, all affected differently by wildfires. While temperate forests have evolved to withstand and even benefit from periodic fires, tropical forests are highly vulnerable to fire, risking biodiversity loss and habitat destruction. By modeling wildfires with a fire regime approach, we aim to understand how fire impacts these ecosystems and why tailored fire management strategies can help to conserve the resilience of temperate forests and protect the ecological integrity of tropical forests amid global changes and anthropogenic threats.

Methodology. To capture the dynamic interaction among weather, vegetation, and human activities we applied the mechanistic wildland fire model (FLAM) developed at IIASA. The model used a daily time step at a 1km^2 homogenous grid across the entire Mexico which requires using IIASA's computing facilities including EBRO and parallel processing techniques. The model was calibrated and validated using a large and detailed data set, including burned areas from 2001 to 2020. Emphasis is put on capturing climate signals during El Niño years and their impacts on burned areas. This is the first application of FLAM in a Latin American country.



Results. An initial analysis revealed that distinct fire drivers exist for different ecosystem fire regimen types, including temperate and tropical forests, shrublands, croplands, and grasslands. In fire-adapted ecosystems, topography and human factors played significant roles; these ecosystems were sensitive to altitude, distance to water bodies, accessibility (i.e., distance to roads), and population density. In contrast, fire-sensitive ecosystems were primarily influenced by extreme temperature and precipitation, human factors, and wind components. Drivers such as wind speed and Fine Fuel Moisture Code (FFMC) were crucial in shaping fire dynamics in these ecosystems. FFMC showed significant correlations with fire frequency and size, particularly in fine fuel-dominated landscapes like grasslands and shrublands. The initial analysis served as a precursor to running FLAM. Current results are being checked as the model requires several iterations to ingest the data properly and produce usable results, which should be available at the end of the YSSP period.

Conclusions. Understanding ecosystem fire regimes is crucial for land management and conservation. Fire-adapted ecosystems benefit from maintaining their natural fire patterns to support biodiversity and ecosystem health, while fire-sensitive ecosystems need careful fire management to prevent damage to vulnerable species and habitats. Activities like fire suppression and introducing non-native species can disrupt natural fire patterns, so aligning fire management with ecosystem fire regimes is vital for ecological integrity and resilience. Implementation of these results in mechanistic wildfire model FLAM can help in assessing the impacts of adaptation options on potential burned areas across diverse ecosystems in Mexico and Latin American countries.

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Building an assessment framework for sustainable land use in the Korean peninsula

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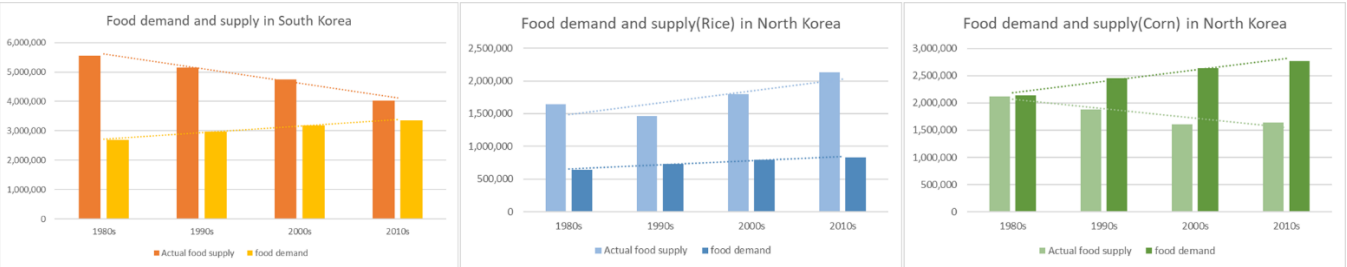
Introduction. Land is an essential but limited resource; thus, there is high competition among land use systems. A major land use conflict relates to afforestation/reforestation (forest land) and agriculture (cropland). Without appropriate land use planning and management, it is challenging to solve land use conflicts and achieve sustainable land use. Therefore, this study aims to build a land use assessment framework for sustainable management between forest land and cropland and provide a first assessment for the Korean peninsula focusing on land use change among the two land use types.

Methodology. The analytical framework is divided into two parts: (1) to build an assessment framework for sustainable land use and (2) to assess the land use in South and North Korea. The assessment framework is built based on literature reviews on the topics of food security and land-based climate change mitigation. Also, it adapts supply and demand on the two land use types for identifying whether individual land uses' supply meets demand. In the cropland, the land use' demand (food demand) is defined as the annual amount of crop yield for self-sufficiency. The real food supply is based on real production from statistical data and potential food supply from EPIC-IIASA. EPIC-IIASA can estimate annual crop yield using climate and environmental data with various management options. On the other hand, forest land's demand (carbon demand) is the amount of carbon emissions using Life Cycle Assessment (LCA). The actual carbon demand to offset agriculture from crop yield is based on statistical data and the potential carbon demand from that in EPIC-IIASA's results. Net Primary Productivity (NPP) from Global Forest Model (G4M) is used as carbon supply.

Results and Conclusion. Almost half of the cropland in South Korea is cultivated with rice. Even though the average of actual rice production decreased from approximately 5,549,631t (tons) to 4,029,023t, the actual supply exceeds the food demand. In the case of North Korea, rice as the major crop takes up one quarter of agricultural land as well as corn. Demand and supply in rice satisfied food security (the ratio of supply divided by demand provided around 200%), but corn shows different aspects. The demand for corn increased whereas the actual supply decreased. Furthemore, the gap between supply and demand is getting bigger. For example, the ratio of supply divided by demand in the 2010s reached only 59%.



This research contributes to manage the land competitions between forest land and cropland by building a land use assessment framework. For further research, the variable data such as crop yield and NPP could be improved by using optimized input data for the Korean peninsula with high spatial resolutions.

Securing Malawi's Water Future

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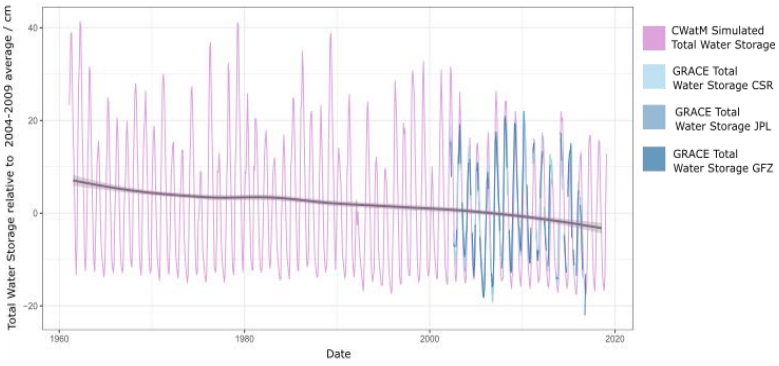
Introduction. Malawi's rapidly growing population alongside development, has led to an increasing water demand, projected to grow over the coming years [1]. Due to these pressures, Malawi's water resource per capita now falls below the definition for 'water scarce' [2]. Groundwater provides the main source of domestic water for around 70% of the population [3]; however, as a largely unseen resource, this can make understanding trends in, and preparing for the future of, national water resources an even greater challenge.

Methodology. We modelled Malawi's water resources using the Community Water Model (CWatM) [6]. To better investigate groundwater changes, we coupled the CWatM model with Modflow [7]. To ensure that the model accurately reflected considerations in Malawi's water resources, we conducted stakeholder interviews identifying gaps and inappropriate assumptions in the CWatM model. We used these to guide modifications to the model. We develop updated spatial input files within the key areas of agriculture, domestic water use, industry, wetlands, aquifer type, and groundwater vs surface water usage. We also provide modifications to the model structure regarding sanitation systems. We applied soft calibration of the CWatM model using GDRC discharge data [4], evapotranspiration data [5] and GRACE Land Water Content data [6].

Results. We identified 4 key areas of focus to better tailor to CWatM model to Malawi from stakeholder engagement meetings. These were incorporating: smallholder agriculture, non-piped sanitation, baseflow, and spatial variation in water sources. We also identified 3 areas that stakeholders are interested in evaluating in the future of Malawi's water resources, these were groundwater recharge, climate change and agricultural intensification. Modelling the change in total water resources from 1961-2019, relative to the average total water storage from 2004-2009, showed a reduction in total water resources from +14.9cm total water storage in 1961 to -1.3cm water in 2019, compared to the 2004-2009 total water storage level. Our results were soft-calibrated and compared to measured changes in total water storage from GRACE Land Water Content remote sensing data [6].



Conclusions. Our results show that there has been a reduction in the total water resources of Malawi since 1961, presenting concerns for Malawi's future water security. Future work will expand our modelling of Malawi's water resources through developing the CWatM model to capture water table changes and groundwater use patterns allowing the simulation of the state of water resources under environmental and social change. As echoed in our stakeholder engagement *'If we continue on the current trends [in water management] it will be tragic'* (personal communication). Building a comprehensive picture of water management in Malawi will be necessary to effectively manage Malawi's fragile water resources.

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Water availability in mountains and its relevance for water supply in river basins globally

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Introduction. Mountain landforms play a vital role in water resources. Orographic precipitation provides mountains with disproportional high precipitation, which can be stored seasonally or over many years as snow and ice. Nevertheless, knowledge about their relevance for lowlands is limited on a global scale, especially beyond long-term annual averages (Viviroli et al. 2020). Therefore, this study aims first to assess differences in the water supply of mountains and lowlands in large river basins globally. Second, the relevance of mountain areas for water supply is evaluated by considering monthly and interannual variability to identify hotspots of mountain importance.

Methodology. A glacier representation was added to the large-scale hydrological model CWatM (Burek et al., 2020). The model was run at a resolution of 10km (5arcmin) globally from 1990-2019 to provide simulations of water availability, water demand and water use. Mountain and lowland areas were compared within each river basin to identify the distinct patterns of water availability in the mountains regarding the water quantity, seasonality and interannual variability. Moreover, water availability from surface and groundwater and water demand for irrigation, industry, domestic and livestock use are contrasted to explore the relevance of mountains for human water demand.

Results. Long-term average precipitation and runoff are disproportionally higher in mountain areas in 78% and 75% of the 629 basins analyzed globally. In contrast, irrigation is disproportionally lower in mountain areas in 82% of the basins. This indicates the potential relevance of mountains in providing water for human use in these river basins. Variability in runoff between months is often higher in the mountain areas of the basins, especially in river basins located in cold climate, whereas interannual variability in runoff is mostly lower in the mountain areas of basins, especially in basins located in temperate and arid climates. For long-term annual average, the non-mountain areas can satisfy their surface water demand themselves in 93% of the analyzed basins. However, differentiating between months shows that for 180 basins, the non-mountain areas cannot satisfy their demand by the runoff generated in these areas in at least one month. Out of these 180 basins, mountain areas can compensate for the entire deficit in 57 basins.

Conclusions. Generally, mountain areas are characterized by disproportionally high precipitation and runoff compared to non-mountain areas in river basins. The relevance of mountains for water supply in lowlands on seasonal and interannual scales is larger compared to long-term annual averages. However, their relevance differs depending on the characteristics of the river basin. Next steps include analyzing the change in the potential relevance of mountain landforms due to future climate and global change and conducting a more in-depth differentiation between mountain types.

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Mapping safely managed drinking water service use in Laos PDR using Earth Observation data

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Introduction. Safe drinking water access is a human right, yet data towards its mapping is lacking, especially at high resolutions. For most low- and middle-income countries, subnational district level data on the global Sustainable Development Goal (SDG) indicator, "*use of safely managed drinking water services*" (SMDWS), is not available for estimating progress towards safe drinking water for all (SDG 6.1) (WHO et al., 2023). Earth Observation (EO) data on anthropogenic and environmental factors provide an opportunity to complement traditional household survey data sources to generate estimates for SMDWS in data scarce regions to inform decision making. Laos People's Democratic Republic (PDR) is estimated to have the lowest coverage of SMDWS in Eastern and Southeast Asia today with only 12% of the rural population and 27% of urban populations having access (WHO, 2023). Laos PDR is an example of a low-income country lacking robust estimates on SMDWS use at subnational and higher resolutions.

Methodology. In this case study, we estimated the use of SMDWS at subnational district levels in Laos PDR using nationally representative Multiple Indicator Cluster Survey (MICS) household data and 22 EO covariates from 2017. We used random forest classification models on a training set of 3290 households from 1165 geo-referenced locations. We then compared the co-variate importance and model performance of different groups of co-variates including models with EO data and household covariates as predictors of SMDWS.

Results. Night lights and built up landcover were the most important EO predictors for SMDWS. The wealth index was the most important household predictor with lower values contributing to lower probabilities of SMDWS use. Our best performing model using only EO data obtained a maximum accuracy of 0.86 based on leave-one-district-out cross-validation metrics and an accuracy of 0.89 based on metrics from the full model using a classification threshold of 0.5 for the prediction probability of unsafe drinking water services. Xaysomboune and Oudomxay had the highest prediction accuracy (0.95) at administrative district level 1 and Vientiane Captial the lowest (0.80). Households located in Luangnamtha and Oudomxay showed the lowest average likelihoods of using safe drinking water. The largest variability in safe drinking water use was identified in Vientiane Capital and Xayabury.

Conclusions. Our study shows that EO data, including both anthropogenic and environmental co-variates, are viable sources of information for filling data gaps at subnational district levels for SMDWS use. Next steps will involve predicting SMDWS at the centroids of a 2 km grid as well as centroids of detected buildings and aggregating these to administrative admin level 2. Furthermore, we plan to test the applicability of our geospatial modelling approach to other countries including Malawi, Georgia, Fiji and Kosovo as well as its potential to use the models to update SMDWS estimates over time.

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A Database for landscape-scale modelling of bark beetle forest damage in Europe

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Introduction. The European spruce bark beetle (*Ips typographus*) is the major cause for premature biotic spruce death in European forests and profits from rising temperatures under climate change. Foresight modelling of bark beetle outbreaks can help forestry and conservation sectors as well as nature-based climate change mitigation efforts. Complementary to the detailed existing process-based bark beetle forest disturbance models, the goal of this project was to find low resolution climate and forest structure predictors for bark beetle damages to Central European forests under climate change for a lightweight bark beetle forest disturbance module compatible with IIASAs in-house models.

Methodology. The main task of the project was to build a database fit for regression analyses. The focus remained on Austria due to time constraints but can easily be extended to other central European countries in the future. Five types of data were collected: (1) Observations-derived historical climate data for Europe for the period 1980-2022 (Copernicus, 2020) (2) Forest characteristics for Europe derived from recent satellite imagery (Pucher, 2022) (3) Geographical details of the Austrian political districts studied in this project (4) Austrian forest inventory data in district resolution for the period 1992-2021 (ARCF, 2022a) (5) Bark beetle and storm damages to Austrian forests in district and state resolution (ARCF, 2022b; FMAFR, 2022). Comprehensive postprocessing included for a big part harmonization of past and present political district boundaries, harmonisation of file types, units and projections from different data sources and filling data gaps. The data was organised into a machine learning algorithm-readable dataset with more than 60 potential predictors, supplemented with a set of further calculated bark beetle-relevant indicators. Subsequently, a multiple regression analysis was carried out in Python.

Results & Conclusions. The main output of this project is the dataset and its accompanying postprocessing scripts with which new data can easily be added. The dataset comprises harmonised climate, forest structure and forest damage data, including among many others, temperature, precipitation, radiation, humidity, windspeed, tree species groups, age classes, stem diameter, tree height and amount of Norway spruce forest for the Austrian political districts. Calculated predictors include overwintering success, converted bark temperature, previous summer precipitation anomaly, amount of daylight hours, bark beetle-relevant degree days, and more. Datasets on which future modelling exercises can be built are an important fundament for the research community and a valuable starting point to further statistical analysis of large-scale bark beetle outbreak drivers in Europe.

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Characterization of initial fire points in equatorial southeast Asia in 2014-2016

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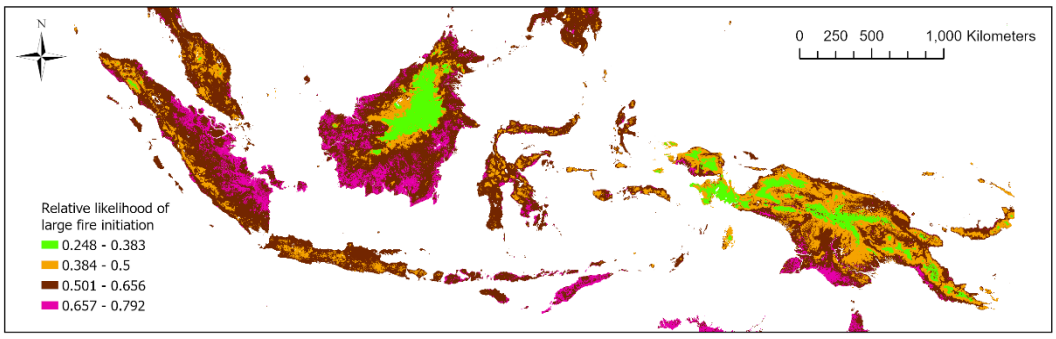
Introduction. Wildfires are major disturbances to ecosystems not adapted to them and can become more frequent and intense as dry seasons get longer and temperatures rise. Fire-related risks may jeopardize the nature-based climate solutions potential identified in Southeast Asia. Nature-based climate solutions rely on the functioning of carbon sinks, like tropical rainforests, that sequester carbon from the atmosphere through photosynthesis. From the fire risk perspective, biomass and necromass accumulation cause fuel material build-up. Enhancing our understanding of forest fires in Southeast Asia is crucial in the success of nature-based climate solutions in the region. This study aimed to estimate the likelihood of large fire initiation across equatorial Southeast Asia.

Methodology. Using the spatial and temporal information of the fire points recorded by NASA MODIS and VIIRS instruments, we linked active fire points detected between 2014-2016 to form networks that distinguished the likely initial points of large fire networks from the fire points that were likely to be caused by the fire spread. These distinctions were made based on the closeness with any earlier detected fire points in the spatial and temporal aspects. We focused on the initial points since understanding the characteristics of ignition sources is pivotal for successful fire prevention. The identified initial points were input into the maximum entropy model (Phillips et al., 2020) that took into account a combination of anthropogenic and biophysical properties of the landscapes. The model's prediction was then used to identify other areas in equatorial Southeast Asia with similar characteristics to the initial points.

Results and conclusion. From the maximum entropy results, the most important biophysical and anthropogenic variables in predicting the likelihood of large fire initiations in equatorial Southeast Asia are elevation and land cover heterogeneity, followed by the ecoregion. The identified areas with similar characteristics to the initial points are shown in the map below. The large fires recorded in equatorial Southeast Asia between 2014-2016 were closely associated with agricultural-land dominated landscapes with high land cover diversity in lowlands. Future restoration and carbon conservation planning should take into account the mapped ignition likelihood to increase their impact's permanence.



Revealing the impacts of agriculture on water sustainability in the Yellow River Basin

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Introduction. As the most populous country in the world, China's food security is challenged by significant agricultural demand, limited water supply and groundwater depletion. Studies have shown that within 10 to 100 years, there may be a limiting shortage of groundwater resources in northern China. As of 2015, about 569 million people live in areas with decreasing water resources. The continuous development of Chinese society and population growth will bring considerable challenges to China's water resources management. This study investigates the water-food coupling system in the Yellow River basin.

Methodology. We prepare the open-source Community Water Model (CWatM) for the Yellow River Basin at 5 arcminute resolution (~10 km at the equator) to simulate the water cycle, including irrigation management and water use of specific crops. We then prepare the Python implementation of the Agro-Ecological Zoning model (PyAEZ) to simulate the crop-specific highest attainable crop yields given soil, terrain, nutrient, and climate constraints. We harmonize the crop stage-specific crop coefficients for water requirement (Kc) and crop yield loss factors between PyAEZ and CWatM to relate relative stage-specific water use of crops $^{ET_a}/_{ET_p}$ with actual yield. Finally, the spatiotemporal distribution of crop yield and water storage are used to assess the impacts of agriculture on water sustainability in the Yellow River basin.

Results. In the 2000 year, our results show that among winter wheat yield and summer maize yield under irrigation and rainfed conditions, the season average $^{ET_a}/_{ET_p}$ from CWatM is 0.50 ± 0.10. The ratio of most areas ranges from 0.40 to 0.60. We also find that the average winter wheat yield and summer maize yield under irrigation and rainfed conditions simulated by PyAEZ is 1575.57 kg/ha, 876.74 kg/ha, 1707.75 kg/ha, 975.80 kg/ha5, respectively. After the coupling of CWatM and PyAEZ, the average winter wheat yield and summer maize yield under irrigation and rainfed conditions are 630.35 kg/ha, 542.94 kg/ha, 1142.76 kg/ha, and 618.72 kg/ha, respectively. At the same time, we also found that the spatial distribution of annual average irrigation water withdrawal, annual groundwater irrigation volume, river diversion irrigation volume and crop yield are very similar. The irrigation areas close to the Yellow River are always high-value areas. In contrast, the mountainous high-altitude regions far from the Yellow River are always low value for all three elements.

Conclusions. The results showed that it is feasible to use the CWatM model to optimize the maximum potential crop yield simulated by the PyAEZ model to obtain crop yields that are more suitable for water constraints in regions with different social development levels. The impact of agricultural activities on water availability in the Yellow River Basin is evident, and coupling CWatM with PyAEZ can more accurately identify areas where water security is at risk.

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Transboundary flow regime management in the Ganges-Brahmaputra Basin under hydro-climatic uncertainty

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Introduction. The Ganges-Brahmaputra basin (GB) is used by 630 million people across five nations and is notable for its sensitivities to climate change and a near-lack of transboundary cooperation. Polycentric water governance in the GB poses a complex problem amid climate-driven uncertainty through which maladaptive action by upstream nations can result in detrimental outcomes for downstream nations and for themselves. The goals of this project are three-fold: (1) to examine how the determination of adequate environmental flow (EF) across borders reflects stakeholder perspectives; (2) to understand how regulation of EF affects decision-making across water users; and (3) to identify characteristics of robust policies that could enable nations to reliably adhere to EF regimes.

Methodology. We applied the ECHO hydro-economic model to the GB to emulate the behavior of water users (domestic, industrial, and agricultural) across the basin under varying hydrological conditions (Kahil et al., 2018). This model highlights complexity in the system due to polycentricity and hydro-climatic uncertainty. The model was leveraged to identify viable opportunities for bilateral cooperation by testing how various EF regimes perform without additional intervention across a range of plausible scenarios encompassing uncertainties. As we uncover these opportunities, we are seeking to evaluate the robustness of bilateral cooperation strategies for enabling the implementation of more aggressive EF regimes without facing an unacceptable risk to economic outcomes.

Results. Initially, we looked at the case of the Farakka Dam, where a treaty (expiring in 2026) governs streamflow in the Ganges River between India and Bangladesh. A new treaty will likely apply revised EF determination criteria (Rahman & Rahaman, 2018; Akter, 2010). Such criteria may include holistic assessments of environmental and socioeconomic needs and more aggressive ones that prioritize restoration of pre-treaty flows. We find that a holistic approach poses negligible economic risk in 34 out of 35 climate scenarios; failure occurs when India's wet season runoff is 14% of its baseline. For increasingly aggressive regimes, reliability decreases to as little as 20 out of 35. It is plausible that bilateral action could improve the reliability of intermediate EF regimes.

Conclusions. Through the above exercise, we uncovered EF regimes that should not be implemented without additional interventions. To conclude the limited study of the Farakka Dam, we seek to leverage precedent and best practices (UNECE, 2021) to test bilateral cooperation (e.g., side payments and cost sharing) that could preserve economic performance as well as sustainable river usage. Extended to the remainder of the GB, we expect to uncover additional vulnerabilities that challenge the determination of EF regimes and the design of cooperative action to avoid maladaptative climate action.

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Downscaling global socio-political scenarios for the Western Mediterranean Sea to test nature-based solutions within an ecosystem-based approach

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Introduction. Global assessments rely on global socio-political scenarios (SSPs) and global policy goals, such as 30 by 30, but for policy assessment a translation into local contexts in terms of management strategies and policies is needed. Marine ecosystem models can serve as tools to assess the impact of different policy objectives on the ecosystem. This project applies an Ecospace marine ecosystem model to evaluate responses of species and ecosystem dynamics to nature-based solutions based on protection and sustainable harvesting and tailored to the Western Mediterranean Sea context. The Mediterranean Sea is a hotspot for biodiversity, climate change and overfishing, highlighting the need for biodiversity conservation and fisheries sustainability.

Methodology. Ecospace is the spatial-temporal component of the Ecopath with Ecosim (EwE) modelling framework. Using a previously calibrated Ecospace model for the Western Mediterranean Sea[1,2], we explored the effect of implementing a bottom trawling fish ban in Natura 2000 sites through two scenarios: 1) baseline SSP1-2.6[1] and 2) banning fishing trawling in Natura 2000 sites from 2024 onwards. We calculated the difference in biomass ratio of the Natura 2000 scenario relative to the baseline. For each scenario, we calculated the ratio between the projected biomass of red mullet (Bf, 2030-2025), an important commercial species in the region and a target of trawling fisheries, with the initial biomass (Bi, 2000-1995).

Results. On average, the ratio Bf/Bi for red mullet in the Western Mediterranean Sea was 5.3% higher in Natura 2000 scenario than the baseline. The predicted biomass was higher under Natura 2000 scenario in several areas, mostly in the Ligurian Sea, the Gulf of Lion and central Spanish coast, with a maximum increase of 645%. The predicted biomass was lower in areas such as northern Spanish coast. The maximum decrease was 52% (Figure 1).

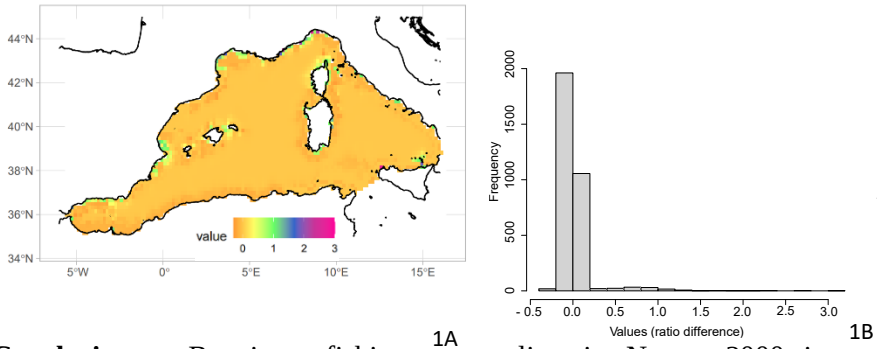

Figure 1. 1A. Difference in biomass ratio among Natura 2000 and baseline scenario for red mullet. 1B. Histogram of change in biomass ratio for red mullet among Natura 2000 scenario and baseline scenario.

Conclusions. Banning fishing trawling in Natura 2000 is predicted to have a positive effect on red mullet biomass by 2030; however, regionally, the magnitude of the change will be minor in the short-term. A higher increase in red mullet biomass is expected in the long-term.

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Economic and Environmental Implications of Alternative Water Policies for Drought Adaptation in South Africa

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Introduction. Globally, water security is a critical concern, especially where demand surpasses supply owing to climate change impacts, population expansion, and economic growth. This complexity drastically increases in many arid and semi-arid regions where climate change alters rainfall patterns and makes extreme weather events more frequent and intense. In South Africa, this has led to increased competition for water resources and exacerbated the difficulty in meeting the needs of different water users (Lukat et al., 2022). This project investigates the potential of water pricing policies and the implementation of water-saving technologies as catalysts for improving water use efficiency in Western Cape Province in South Africa.

Methodology. We used a hydro-economic optimization framework that integrates water availability and economic benefit patterns for urban and agricultural demand at various locations in a river basin (Kahil et al., 2018). The model integrates both river water flows and agents' behaviour, while specifically analysing the effects on water use of urban and agricultural infrastructure modernisation and water pricing policies at river basin scale in the Western Cape Water Supply System (WCWSS). The model also assesses four levels of climate-induced water scarcity relative to the base levels: 0%, 30%, 50%, and 80% as percentages of the historical baseline. The hydrological component is a node-link network of supply nodes such as rivers and dams, and demand nodes such as urban use and agricultural demand (irrigation).

Results. The initial model analysis showed the possible economic benefits that can be achieved when the water allocation objective is to support the production of high-value water users in water-scarce regions. It also shows that the adaptation of irrigation districts to drought consists of modifying the crop production pattern towards more profitable crops and the use of efficient irrigation systems. The preliminary findings also suggest the potential of water pricing policies and the implementation of water-saving technologies to increase water allocative efficiency and enable farmers to produce more with less water.

Conclusions. The approach of this study demonstrates both the goals and means of allocating water systematically among sectors and ensuring maximum benefits in large water systems under varying water availability conditions. The water availability scenarios and the ensuing social welfare under the policies considered provide important information to support decision making. This study also supports initiatives that prioritize environmental flow requirements at the river mouth during droughts in the region and contributes to long-term water security objectives.

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Advancing Systems Analysis (ASA)

Linking R&D investment to emission reduction cooperation: overcoming free-riding while achieving deep de-carbonization

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Introduction. To effectively combat climate change, we must achieve international cooperation among sovereign nations. However, it has proven difficult to construct international agreements without supra-national authority: nations have strong incentives to free-ride, collecting the benefits of reduced carbon emissions while avoiding associated efforts. In this project, we propose and analyse an incentive mechanism that helps to promote self-enforcing climate cooperation while achieving deep de-carbonization, in which a link between R&D investment and emission reduction cooperation is established. A game setting is employed to theoretically explore how and under which conditions the mechanism works. A multi-regional Integrated Assessment Model (IAM), allowing for the formation of coalitions under realistic assumptions is built to examine the mechanism empirically. Policy implications are discussed.

Methodology. (1) Game theory. Countries decide whether to join a designed climate agreement knowing that signatories determine abatement effort by maximizing the coalition's combined welfare while non-signatories maximize their own welfare. By utilizing both internal and external stability conditions, analytical solution for determining the size of a stable self-enforcing coalition and the corresponding total emission level are provided. (2) Multi-regional IAM. An empirical study employs an adapted 12-region RICE model where the incentive mechanism is incorporated together with the underlying game. Key parameters for the model are estimated, followed by the calculation of gains and losses resulting for each region from joining a coalition. An enumeration algorithm is implemented to find self-enforcing stable coalitions.

Results. Theoretical analysis gives us an intuition that for a sufficiently low ratio of the marginal damages of emissions to the abatement-cost parameter, the incentive mechanism can promote cooperation and meanwhile achieve deep de-carbonization. Conversely, when this ratio is sufficiently high, the incentive mechanism cannot achieve either goal. If the ratio falls somewhere in between, the mechanism can only achieve one of the goals. From the empirical analysis we conclude that, without incentive mechanism, there is no stable coalition and in such non-cooperative equilibrium the resulting abatement level is low. By contrast, the incentive mechanism enables formation of stable coalitions for all considered sets of model parameters (scenarios). The stable coalition size ranges from 2 members to 8 members (out of 12) depending on the scenario. The economic gains range from 3.2 billion USD to 235.3 billion USD in a modeled year. Besides, under this mechanism, emission reductions rates of 14% can be attained per year. The model regions EU, Latin-America, "Other Asian countries" and US appear most frequently among coalition members – the respective percentages of scenarios are 100%, 96%, 82%, and 60%.

Conclusions. Given the negative externality of climate change, free-riding is naturally expected when it comes to combatting climate change. The costs of abatement are national, while the benefits are global and independent of where the emission reductions take place. This study explores an incentive mechanism that links R&D investments to abatement cooperation, fostering not only self-enforcing abatement cooperation but also inducing "additional" reductions in emissions due to advancement of emission-reducing technologies by joined R&D funding efforts. These aspects are important for achieving ambitious climate targets.

Integrating time series data with epidemiologic models to improve prediction of COVID-19 dynamics in China

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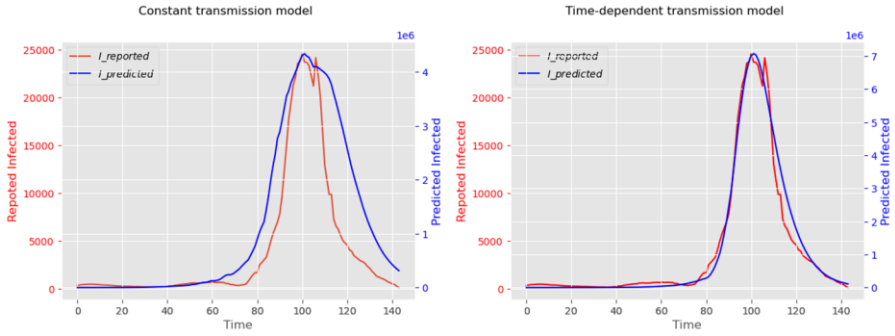
Introduction. There are two main approaches to predicting epidemic dynamics: statistical models and mechanistic models. Statistical models excel in predictive precision but lack interpretability by focusing solely on data patterns, disregarding underlying mechanisms. Conversely, mechanistic models explicitly include biological and epidemiological knowledge of the epidemic, offering intuitive insight. Yet, reliance on assumptions and simplifications may limit their real-world predictive capability. This study merges these methods by incorporating empirical mobility time series data into mechanistic epidemic models, to enhance their predictive accuracy.

Methodology. We employed the widely used Susceptible-Exposed-Infected-Removed (SEIR) model to forecast epidemic dynamics, aiming to enhance its predictive capability. To achieve this, we introduced the time-dependent transmission rate parameter and established the relationship with the mobility time series. While SEIR operates continuously, real-world data is often collected discretely. Additionally, compartments in the SEIR model are not directly observable. To address these challenges, we developed a state-space model based on SEIR. Bayesian estimation is employed to fit this state-space model. In this model, the observation focuses on the growth rate of infected individuals, while the hidden states encompass the values of the four compartments. To assess the impact of incorporating mobility data, we've calculated the Bayesian information criterion (BIC) for both constant and time-dependent transition rate models.

Results. We conducted a fitting analysis for COVID-19 confirmed cases in Shanghai, China, spanning from January 12, 2022, to June 5, 2022. We developed models with constant and time-dependent transmission rates. Notably, the time-dependent transmission rate was inversely proportional to the square of the "urban travel intensity" time series. We employed the Bayesian Information Criterion (BIC) to evaluate the predictive accuracy of both models. The fitting outcomes revealed that the model with a time-dependent transmission rate is slightly better, with a lower BIC value of -546.866 compared to -543.635 for the other model. Both models succeeded in capturing the peak infection time, but the time-dependent transmission rate model 2 demonstrates higher precision. However, both models generated infection estimates substantially exceeding reported values.



Conclusions. In conclusion, our findings can be summarized in two main points. Firstly, we have developed a Bayesian state-space model that extends the traditional SEIR model. This model incorporates more realistic time-dependent transmission rates, which respond to changes in mobility patterns. Secondly, the inclusion of mobility data has a positive impact on the accuracy of predicting the timing of peak infections.

National strategy analysis towards mutual achievement of SDGs: A method coupling dynamical model and improved network hierarchy analysis based on SDG targets interactions

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Introduction. The UN's 2030 Agenda features 17 sustainable development goals (SDGs) with 169 targets, necessitating worldwide endeavours to conquer sustainability challenges. National action plays a pivotal role, thus amplifying the significance of local sustainable development strategies. Past research employed diverse reductionist, systematic, and combined approaches to devise these strategies. Yet, the intricate cascading effects stemming from interwoven SDG interactions and the nuanced interplay of temporal and resource priorities have often been overlooked. This study pioneers an innovative amalgamated approach, systematically assigning temporal and resource priorities to individual targets. This methodological advancement strives to optimize system efficiency, propelling synergetic SDG achievement.

Methodology. We introduce a tri-dimensional model to allocate temporal and resource priorities for SDG targets. This model hinges on differentiating between two types of priorities based on three facets: (a) target trends over time, (b) target interactions' influence on progress, and (c) an individual target's systemic impact. These facets shape the model's dimensions, analyzed via Mann Kendall trend analysis, an enhanced dynamical model, and an improved network hierarchy analysis. We demonstrate this method using China's target-specific interaction network and target time series data from the Institute for Global Environmental Strategies (IGES) dataset.

Results. We have formulated concrete strategies for individual targets to foster the collective attainment of SDGs. These strategies encompass varying levels of temporal and resource priorities for each target. Statistical analysis of temporal priorities unveils that 10.7% of targets require urgent action for promotion or blocking relevant trade-offs, while 63.6% and 23.8% demand moderate and low levels of urgency, respectively. Among targets with high temporal priorities, three are prime candidates for promotion due to positive impact and descending trends, focusing on energy efficiency and augmented funding for forest management and biodiversity preservation; 18 targets confront influential trade-offs but have upward trends, predominantly within Goals 2, 3, and 15. Concerning resource priorities, 27.4% of targets necessitate elevated resource allocation due to impeding interactions between the SDGs, whereas the remainder benefit from moderate resource priorities driven by reinforcing interactions. High-resource priority targets cluster primarily within Goals 12, 15, and 16.

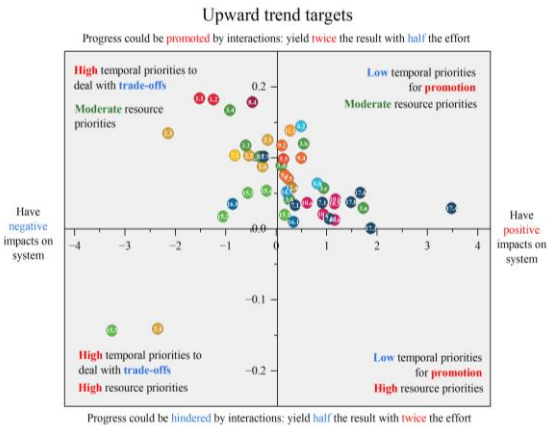

Figure 1. Formulated strategies for upward trend targets

Conclusions. We developed a novel tri-dimensional model that tailors specific strategies for sustainable development by harnessing interactions within the complex sustainability framework. Validation experiments using the iSDG-China model demonstrate the efficacy of these strategies, resulting in an average of 4.72% additional net progress per goal compared to the baseline scenario. Therefore, we recommend swift actions to enhance funding for biodiversity preservation and forest management, and to foster energy efficiency measures. Additionally, allocating extra resources to the responsible consumption goal is imperative due to pronounced trade-off effects. Conversely, efficient resource allocation can curtail inputs for climate action, capitalizing on the synergistic effects of other objectives.

Justice preferences in urban climate adaptation flood policy

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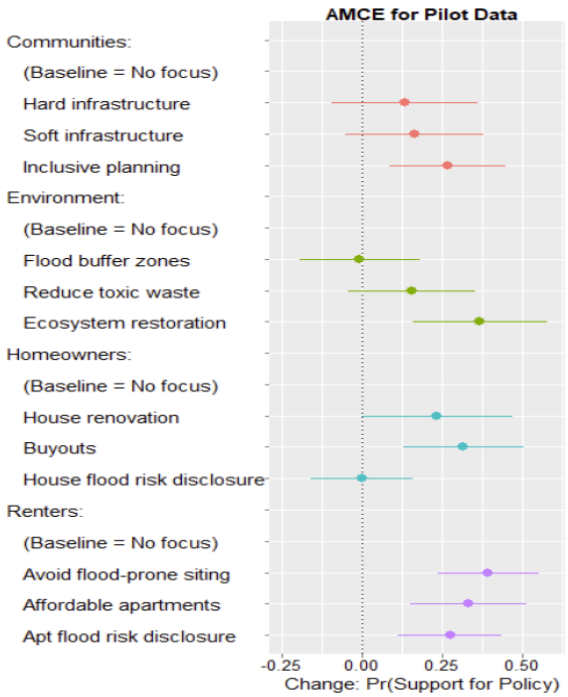
Introduction. The need for ex-ante climate adaptation policy design is ever increasing in urgency as climate-related disasters continue to increase in frequency and severity. One set of climate adaptation policies ripe for consideration – especially from an equity and justice lens – is risk management for worsening flooding. This project designed and tested an online survey that will examine the variegated values that underlie urban residents' flood policy preferences, as well as their differing perceived experiences with extreme weather disasters, inequality, and political engagement.

Methodology. We designed an online survey intended for 5 urban locations globally: Buenos Aires, Johannesburg, London, New York City, and Seoul. First, we identified the cities via a most-similar criteria selection process, while also allowing for a wide geographic range. Second, we underwent an iterative survey design: 1) drafting the survey in English; 2) collaborating with colleagues from each city to check for cultural fit and returning to (1) as needed; 3) utilizing DeepL and Google Translate for translations and back-translations in Spanish, Zulu, and Korean; 4) collaborating with *different* colleagues from each city to edit the translations and returning to (1) as needed. Third, we took necessary administrative steps for survey implementation: negotiating with a survey panel company, Cint/Lucid; obtaining project approval by an institutional ethics review committee; pre-registering planned statistical analysis with Open Science Framework; and building the online survey using Qualtrics as well as custom CSS and Javascript. Fourth, we pilot-tested the survey with academic colleagues, as well as with NYC residents via Prolific. Finally, we are preparing for full survey implementation, with 650 participants expected in each city (total n=3,250).



Results. This project focused on intricate survey design and the translation process, and was successful in building a robust survey instrument based on the literature and compatible across various locations/languages. Analysis in R of small-scale pilot data suggests that participants *do* distinguish between the provided policy options (which highlight different equity/justice features). Future analysis of the large-scale city data will help determine key predictors of differences in these policy preferences.

Conclusions. We aim to better understand how equity and justice are conceptualized within climate adaptation flood policies. The survey is designed to test the hypothesis that self-identified vulnerability to flood risk more strongly predicts differences in policy preferences as compared to city of residence, political identity, or other demographics.

Modeling northeast Atlantic marine food webs under environmental global change

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Introduction. Sea surface warming and commercial fishing are prominent contributors to global environmental change causing gradients in numerous key variables that can alter marine food webs. Food webs are ecological networks that can be used to quantify key ecosystem characteristics, such as ecological resilience. The aim of this project is to predict marine food webs under the influence of sea surface warming and commercial fishing based on the size-class foraging behavior of species. Here, the overall goal is to develop a robust modeling framework to understand the future of food webs in the northeast Atlantic.

Methodology. A total of 732 marine food webs were constructed from 1992 to 2016 at a spatial scale of 44 000 km^2 across the northeast Atlantic using a novel stomach contents database (Dapstom 2014). These empirical food webs were used to calibrate the Allometric Diet Breadth (ADBM) (Petchey *et al.*, 2008) and Fluxweb (Gauzens *et al*., 2019) models, which together predicted weighted food webs based on key allometric principles. Ecological metrics were calculated from the modelled food webs and were spatially and temporally linked to sea surface temperature (SST) and commercial fishing open-source data. The relationship between the environmental variables and the ecological metrics was investigated using Bayesian additive regression tree models.

Results. The empirical food webs were largely size structured as the ADBM model predicted food web structure to a 93.2 % accuracy. The results highlight the spatial and temporal variation in food webs across the northeast Atlantic. Metrics including the number of nodes, connectance, link density, modularity, number of trophic levels, redundancy and robustness were found to have a significant relationship with SST and commercial fishing.

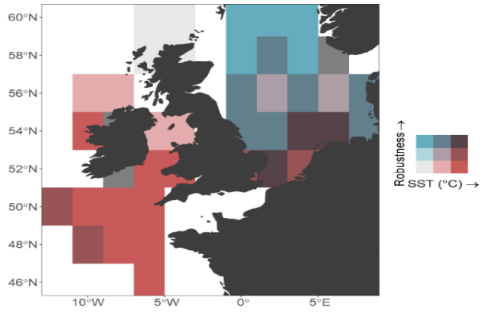

Figure 1: A bivariate distribution map of SST and food web robustness across the northeast Atlantic. These preliminary results suggest that food webs become less diverse in both species and trophic interactions resulting in less robust trophic pathways with an increase in SST i.e., less ability to trade-off efficiency and redundancy, which are key in fostering ecological resilience (Ulanowicz *et al.,* 2009).

Conclusions. Global environmental change has caused changes in food web structure and function in the northeast Atlantic, which is likely to continue into the future. The preliminary results suggest that food webs become less robust and therefore less resilient in the northeast Atlantic with a rise in sea surface temperature and commercial fishing. Such results provide insight into ecological resilience across multiple scales and thus potentially providing the necessary scientific advice for climate change and sustainable fisheries management.

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Unlocking the potential of visualization techniques for disaster risk management (DRM) pathways in multi-risk systems: from data to decisions

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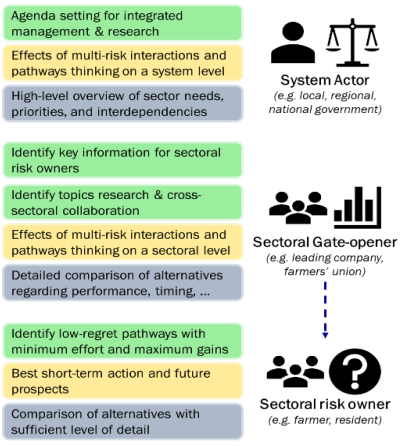
Introduction. Managing multi-risk systems involves understanding intricate relationships between interconnected sectors, or regions affected by various hazards. Impacts from one hazard can spread to other systems, with disaster risk management (DRM) measures potentially causing unforeseen consequences. Deep uncertainties, including climate change, make DRM decision-making complex. Effective tools are needed for policy evaluation in these systems. Schlumberger et al. (2022) proposed an analytical framework to design and analyse DRM strategy alternatives. However, tools for effective communication are still lacking. Information visualization methods can support decision-making but require user-centred considerations. This study develops and analyses visualization techniques for multi-risk DRM pathways, validated by expert feedback.

Methodology. The methodology applied is rooted in Munzner's (2009) systematic design process. Central to the approach is the validation of design choices, ensuring that the designs effectively address user needs and visualization accuracy. We identify user groups, and their analysis tasks, refined through expert insights from various fields. The tasks, once pinpointed, are translated into the broader language of information visualization, consolidating visualization needs. Simultaneously, case study data is examined to discuss necessary data transformations. Finally, suitable visual representations and interaction methods, gathering feedback on them from stakeholders and experts are determined.

Preliminary Results. Incorporating constructive expert feedback on the users and analysis objectives, we characterized the decision context for multi-risk pathways as a collaborative learning process. We identified a set of five analysis questions to be explored using visualizations. We developed a data transformation flow discussing the key dimensions of complexity of multi-risk pathways. Combining data characteristics, analysis objectives and users, we identified a set of five different visualization approaches, including heatmaps, parallel coordinates plots, stacked bar diagrams and various forms of scatterplots to allow users to interactively explore the analysis questions. Validation of the utility of these visualizations by means of a survey is ongoing.



Conclusions. In this study, we engaged in in-depth discussions about the user-centred aspects of complex data visualization. We offer ample justification for the choices made during the design process and offer evidence for the utility of certain visualization techniques, through the collected feedback from domain experts and a wider audience. As such, the study may serve as a first step in the domain of multi-risk DRM to advance and discuss visualization approaches for complex, user-centred information visualization.

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Estimating inequality using nighttime lights and machine learning

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Introduction. Understanding inequality and its drivers in lower- and middle-income countries is hobbled by limited or absent recent data on inequality. Nationally representative household surveys are primarily used for measuring inequality, but they are very expensive and time-consuming to produce at a regular frequency and finer spatial scale. The study focuses on filling the data gaps by developing reliable wealth inequality estimates by combining nighttime lights with other satellite imagery. The result of this analysis is aimed at impact policymaking on social assistance spending in India. This study's theoretical, methodological, and analytical advancement supports advancing Sustainable Development Goal 10: Reduced inequality and other socio-economic indices globally.

Methodology. The study draws household asset information from the Demographic and Household Survey (DHS) dataset. It estimates the wealth index for each household by obtaining the first components from Principal Component Analysis (PCA)[1]. Further, it computes the Gini coefficient of household wealth distribution at the DHS cluster level. The cluster-level Gini coefficient is used as reference data (outcome variable) in the model. Predictors at 2- and 5-kilometer buffers for rural and urban clusters are extracted from nighttime light, crop area, forest, area, urban built-up, NDVI, settlement footprint, population, distance to the administrative center, and distance to national highway. Random forest and XGBoost models using cross-validation are used to analyse the data. Finally, model performance is evaluated using Mean Squared Error (MSE) and R-squared (R2) values.

Results. The preliminary results find nighttime light is the most important feature contributing 0.45 of the total variation of impact on the model's prediction performance, followed by crop area (0.13), settlement footprint (0.07), crop yield (0.06), total population (0.06), per-capita radiance (0.05), distance to the administrative center (0.04), and distance to the national highway (0.04). The random forest model reports a 58% correlation (MSE = 0.008), and XGBoost reports 59% (MSE = 0.0081) between predicted and survey-based wealth inequality. The analysis is constrained by limited reference data, which likely impacts the accuracy of the estimated wealth inequality at a finer spatial scale. In future work, robustness assessments in other countries with diverse inequality settings will be done to validate its preliminary findings.

Conclusions. While the association between nighttime lights with wealth or economic well-being is well established, this study analyses the association between nighttime lights and wealth inequality. The preliminary results demonstrate how satellite imagery and machine learning models can be used to estimate wealth inequality. The study reveals that nighttime light is the most important feature in explaining wealth inequality. It is challenging to measure household-level wealth inequality using satellite data. However, results from this analysis could be used as a substitute for inequality in the absence of subnational-level data for determining development policies.

[1] https://dhsprogram.com/topics/wealth-index/ (Household variables used in PCA are housing: floor, roof and wall material and toilet facility, socio-economic: agricultural land, livestock, educational qualification, dependency ratio, bank account and below poverty level, durable assets: television, refrigerator, motorcycle, mobile, bike and utilities: clean drinking water and clean cooking fuel)

A functional connectivity approach for exploring interactions of multiple ecosystem services in the context of agricultural landscapes

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Introduction. Understanding the interactions and complexities of ecosystem services (ES) is a compelling yet challenging aspect of conservation and sustainability sciences research. Land-use and land-cover patterns, including their spatial heterogeneity and configuration, shape the ecological processes, functions, and services that emerge from a landscape. This research investigates the functional connectivity of multiple ES within a complex landscape, i.e., the flow of ecological processes and services across spatially interconnected landscapes, for example, from pollination provisioning areas to croplands. The primary goal of this research is to develop a conceptual framework that encapsulates 'network topological' interactions specific to agricultural landscapes and then apply this framework to the Canadian prairies, delving into the trade-offs and synergies of the functional connectivity of multiple ES.

Methodology. The two-phase methodology uses the spatial tools InVEST, ARIES, and GIS to map diverse ES, including pollination, carbon storage, agricultural food production, wetland-based ES, and soil erosion control. An ecological network is then constructed for these ES at the landscape scale, designating network nodes based on high-value ES provisioning areas and defining links between pairs of ES according to their functional connections (overlapping on the physical space). These functional connections effectively delineate areas of the landscape where the majority of ES flows occur. ES network linkages were analyzed through flow dynamics and information indices, setting the stage for discussions on network resilience regarding ES provisioning and landscape-scale connectivity.

Results. ES mapping and network building revealed that around 29% of the landscape lies within functional connectivity zones. Although soil erosion control spans just 1.36% of the total area, a substantial 72.59% of its spatial extent was identified as functionally connected. Land cover analysis revealed that natural habitats such as shrublands, broadleaf forests, wetlands, and grasslands are vital mediators of ES. The variability in ES interconnectivity in the landscape was evident both in the intensity of interactions and observed connections. Flow path analysis, using utility analysis matrices, highlighted synergies between soil erosion control and wetland-based ES from marshes and swamps and between pollination and carbon storage.

Conclusions. Our findings reveal the complex dynamics underpinning the interactions among various ecosystem services. While correlation values between pairs of ES provide insights into strong interdependencies and some unanticipated trade-offs among services, they may not capture indirect relationships between various ES. By leveraging connectivity and flow-based metrics, our method unveils previously obscured patterns of ES, such as the interdependencies between soil erosion control and wetland-based ES, and offers deeper insights into the underlying mechanisms of ecosystem interactions. For advancing ecological conservation sciences, our insights emphasize the need for integrating the concept of connectivity and systems thinking with conservation sciences to achieve sustainability and build resilient ecosystems. Furthermore, based on the Ecological Network Approach (ENA), our framework provides a practical foundation to explore the optimal scenarios of ES provisioning at the landscape scale.

A systems-based approach for modelling and assessing pollination provision networks in agricultural landscapes

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Introduction. The global food system is highly dependent on a range of ecosystem services. One such critical ecosystem service is pollination provided by bees. Along with managed honeybees, native bees can provide efficient and stable pollination services as long as there are good quality habitats in surrounding areas. As production of insect-pollinated crops continues to grow at the same time as declines in bee populations are observed due to pests, pesticides, and climate change, there is a need to understand and quantify the supply and demand of pollination services in agricultural areas. The objective of this study is to develop a landscape ecological network framework for evaluating current pollination models and understanding spatial dependencies for pollination services, as well as pointing optimal areas for restoration.

Methodology. We leverage a well-established model of relative bee abundance developed by Lonsdorf et al. (2009) to build landscape-based networks for understanding pollination provision flows through landscapes. This framework provides a unique opportunity for spatially linking supply and demand and model landscape management scenarios. To demonstrate its feasibility, we apply the framework to areas primarily characterized by agriculture with pollination-dependent crops in Washington, California, Michigan, North Dakota, Pennsylvania, and New York, USA. The networks are analysed with Ecological Network Analysis and landscape metrics. Subsequently, we use an integer optimization model with the objective to maximize pollination services via allocation of restoration and/or crop expansion areas across landscapes.

Results. Restoring natural areas rather than expanding agricultural areas may provide the best benefit to increase expected total pollination service, and potentially crop yield, of insect-pollination dependent fruits. The extent of restoration for pollination benefit, however, is sensitive to the level of increase in bee habitat quality and capacity. Analysis of 40 locations indicate that there are correlations between landscape composition and network metrics. In particular, it was observed a negative correlation between Shannon entropy and Total System Throughflow (TST) in diverse, but agriculturally dominated landscapes.

Conclusions. We show that analysing the model developed by Lonsdorf et al. (2009) with an ecological network perspective can aid in the delineation of restoration prioritization and targeted efforts for improving habitats according to pollinator health task force policies. We find that the framework also allows for an understanding of the implications of the assumptions of the model and land-use dependencies.

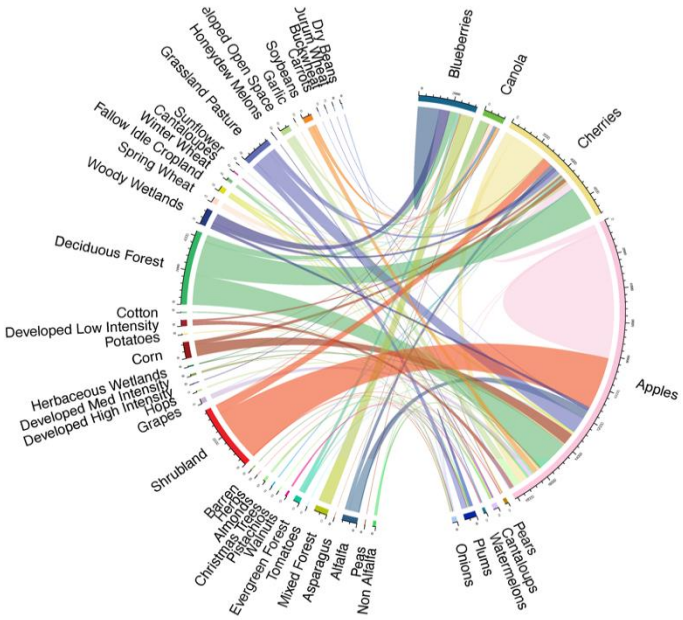

Figure 5: Chord diagram of pollination service flows, summarized for all locations by landscape category. Flows are from left section towards right section.

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Fighting misinformation in social media

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Introduction. Online social media is an important and significant source of information as well as a forum for public debate. Misinformation is false or inaccurate information according to the best factual evidence that is available at a given point in time. Some climate change misinformation challenges the contribution of the human factor to climate change. The discussions related to climate change online in general and on social networks in specific are not well understood. This work analyzes the discussion of climate change on social media to get a better understanding of the conversation and how misinformation affects it. To achieve this, we collected and analyzed a large number of tweets over a long period of time.

Methodology. We used Twitter's academic research API access to collect 350,352 tweets in English and Italian between January 1, 2022, and May 31, 2023, using search queries that focus on the discussion of man-made climate change. We computed the language agnostic sentence embeddings of each tweet. We clustered the dataset into four clusters using the K-means algorithm. The clusters were individually analyzed for the most common words, most referenced websites, time series analysis, and statistic tests to identify significant differences between the clusters.

Results. We used t-SNE to visualize the dataset. The figure presents the dataset with each cluster represented in a different color. The blue cluster discusses policy and peaks when the IPCC AR6 report was published. The orange cluster discusses climate change in general. The green cluster discusses counter-conspiracy to anthropogenic climate change, and the red cluster spreads conspiracy theories related to anthropogenic climate change. The general, counter-conspiracy, and conspiracy clusters peaked following a record-breaking heatwave, and at the beginning of COP27. Furthermore, we found that the counter-conspiracy cluster generally refers to authoritative and academic websites, whereas the conspiracy cluster generally refers to websites that serve user content. Significant differences were observed in the number of replies and retweets between the policy cluster and all other clusters, and between the conspiracy cluster and all other clusters. Significant difference in the number of likes were also found between the policy and conspiracy clusters.

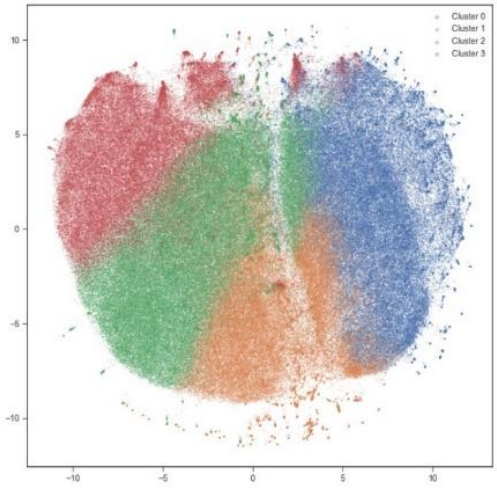

Figure 1. Dataset visualization.

Conclusions. The findings in this work provide an overview of the narratives used in the discussion on anthropogenic climate change on social media. The findings regarding the significant differences between the user engagement metrics in the different clusters also help achieve in-depth understanding of how much users engage in each narrative. Achieving better understanding of the narratives can help authorities and decision makers to develop awareness measures while using important communication tools such as social media.

Impact-defined global temperature targets: unilateral vs. multilateral approaches

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Introduction. The Paris Agreement seeks to significantly reduce climate change risks by updating Nationally Determined Contributions every five years. These contributions differ between small island states, developing states, and Northern states due to varying risks and motivations. Quantifying localized climate impacts remains challenging, though some studies attempt to gauge exposure under warming scenarios. Presently, the agreement sets a unique and global temperature change goal. However, the impact exposure for a same global temperature target differs between countries and therefore the motivations to respect the agreement also differ. Here, we investigate a case where countries do not follow the agreement but align their emission pathways with country-specific impact exposure acceptance thresholds. In other words, we propose a reverse scenario-making approach that translates impact targets into emission pathways, addressing global-to-regional linkages.

Methodology. Using Werning et al.'s (2023) data, we link country-level population exposure to climate impacts (namely droughts, heatwaves, precipitations, water stress) with global temperature, using 0.01°C interpolated intervals. This allows to set acceptable targeted temperature changes for each country. Using AR6 data (Byers et al., 2022), we link temperature to non-CO_2 radiative forcing targets. Simple analytical models then generate pathways towards these targets, used as input for Pathfinder (Bossy et al., 2022). The output provides CO_2 emission pathways aligned with global temperature goals. Sharing quotas downscale emissions to countries. This unilateral approach offers country-specific emission paths tied to 7% exposure thresholds, forming a novel global trajectory. A population-weighted average temperature target is also established.

Results. The unilaterally defined global temperature targets range between 1.2°C and 3.5°C with a mean at 2.18°C. Calculating the population-weighted average gives a multilateral temperature target of 1.79°C. Following the method previously described, we find a global temperature of 1.9°C in 2100 showing that cooperation in fixing temperature targets is more effective to limit climate change than acting unilaterally. This is because high emitters like the United States or the European Union have high temperature targets (around 1.9°C for the US and above 2°C for all European countries) while most Latin American and African countries aim at 1.2°C targets. However, these results consider the combination of the four impacts. Considering impacts individually can lead to a configuration where the unilateral strategy is more effective than a multilateral strategy if high emitters have lower climate targets. Interestingly, European countries appear to have among the highest targets, and are therefore among the less impacted countries, for all impacts taken either together or individually.

Conclusions. Overall, we establish a functional relationship linking country-level damage in terms of population exposure with corresponding temperatures that were translated in temperature and non-CO_2 radiative forcing (RF) timeseries. We create sharing quotas for annual emissions that directly translate the targeted climate change pathway into national emission pathways. Finally, we realize a comprehensive country ranking comparing the initial temperature target at the country level and the final temperature issued from the CO_2 emissions decided unilaterally. We quantify gains and losses under unilateral emission targets, assessing the magnitude of benefits in a harmonized emission pathway scenario.

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Knowledge co-production and assessment of local actions for the achievement of locally relevant socioeconomic and environmental Sustainable Development Goals

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Introduction. The Agenda 2030 established a global framework to address socioeconomic and environmental challenges through 17 Sustainable Development Goals (SDGs) (UN 2015). Achieving these goals demands transformative changes across various sectors and levels. However, the complexity of interrelated systems and uncertainties in external factors pose challenges for policymakers. Integrated assessment models (IAMs) have emerged as tools to understand these complexities, but solely relying on them isn't sufficient to guide us through the complexity of the system. Embracing a transdisciplinary approach and co-producing knowledge with stakeholders offers a promising strategy to achieve local sustainability.

Methodology. This study encompasses six steps. Two face-to-face workshops, with Goulburn Murray's stakeholders, were conducted. Initially, we co-designed the Local Environmental and Socioeconomic Model (LESEM as an IAM tool) to analyse four local priority SDGs. Subsequently, we co-developed local actions tailored to the region's needs. We then specified global scenario assumptions. Utilising LESEM, we simulated the implications of these local actions within two global scenario frameworks. The outcomes were analysed using a co-production approach with local stakeholders. Additionally, we utilised the storyline technique to convey quantified findings to engage the local community.

Results. We developed 11 targeted actions to assess the effects on eight SDG indicators of four priority SDGs: clean water and sanitation (SDG 6), agricultural activities (SDG 2), economic growth (SDG 8), and life on land (SDG 15). The results showed trade-offs and synergies in implementing global and local sustainability actions. Global actions such as dietary changes and food waste reduction, though aligned with global sustainability objectives, presented trade-offs that adversely affected local economic growth. This was evident in reduced dairy production due to the FLX diet shift. Such a decrease may conflict with local preferences, as many rely on dairy farming. The results emphasised the positive impact of local actions on sustainability and the need for complementary actions in water management, skilled workforce, water salinity, and green-blue algal bloom management.

Conclusions. This study highlighted that a comprehensive knowledge co-production with local stakeholders enhanced the salience and legitimacy of the quantified information derived from our local system dynamics model and presented a holistic approach to addressing local sustainability challenges. We illustrated how future trajectories under diverse global and local scenarios have distinct implications for this area. We aimed to encourage the local policymakers to proactively prepare for and adapt to various potential futures by defining and implementing new resilience policies aligning with global and local sustainability priorities.

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Citizen science in air quality monitoring: Opportunities, challenges, and the path forward

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Introduction. Despite extensive research on air pollution disparities, tangible actions are lacking. Traditional top-down air monitoring often misses localized sources and fails to involve communities. A more inclusive citizen science approach promises to address these gaps. However, citizen science faces hurdles like data reliability, standardization, participant retention, and technological limitations (Fritz et al., 2022). This research explores the potential of low-cost sensors in community air quality monitoring, spotlighting the challenges in citizen science initiatives for effective air monitoring. These include, among others, data reliability, calibration, and participant engagement. Actionable guidelines recommend clear goals, calibration processes, and fitness-for-purpose evaluations before sensor deployment to improve community initiatives' policy relevance. Addressing these is pivotal for integrating citizen-generated data into evidence-based policymaking to combat air pollution disparities.

Methodology. Our research addresses challenges and guidelines for community-level air monitoring using low-cost sensors. We conducted a structured literature review from 2012-2022, yielding 149 relevant studies. We employed bibliometric techniques to identify trends, revealing a rising interest in citizen science and concerns around pollution management. Furthermore, experience from a pilot project deployment of 47 outdoor particulate matter sensors in two cities provided additional guidance. Using an evidence co-creation framework (Mahajan et al., 2022), challenges and opportunities were identified and supplemented by a post-deployment survey. Our findings provide a combination of theoretical understanding and practical experience, aiming to offer evidence-based guidelines for future air monitoring projects.

Results. Challenges across *mapping*, *sensing*, *analyzing*, and *sharing* encompass various issues that researchers must address to achieve intended outcomes. Some of these include scientific rigor versus public engagement, ethical considerations, and research question alignment. Siting challenges involve data quality due to local effects, exacerbating inequities, and sensor placement. Technical literacy, low-cost sensor data quality, and data storage are also concerns. Pre-processing, QA/QC, data heterogeneity, visualization, and open access pose analysis and sharing challenges. Guiding principles include clear protocols, stakeholder engagement, ethical guidelines, and diverse recruitment strategies. Collaborating with ethics committees aids ethical considerations. Careful sensor siting, technical training, and ongoing support improve data quality. Calibration, validation, and quality checks enhance data reliability. Standardization, expert collaborations, and clear QA/QC protocols address data heterogeneity. These guidelines inform the complex interplay between paradigms and fitness-for-purpose tiers, aiding successful citizen science project design and execution for air quality monitoring.

Conclusions. Citizen science projects offer invaluable insights into environmental pollution through public engagement, data collection, and collaborative analysis. While these projects amplify knowledge and awareness on pollutants, they grapple with challenges, particularly in balancing scientific rigor with public engagement, data quality, and sharing protocols. To advance citizen science from a contributory to co-creative paradigm, clear protocols, technical support, and standards need to be followed across mapping, sensing, analyzing, and sharing steps. By empowering communities and influencing policy, citizen science can reshape our comprehension of environmental threats, catalyzing more informed and inclusive solutions for a healthier future.

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