FREDERICK S. PARDEE CENTER
FOR INTERNATIONAL FUTURES
*EXPLORE UNDERSTAND SHAPE*

WORKING PAPER 2019.10.04

# FORUM ON SCENARIOS OF CLIMATE AND SOCIETAL FUTURES: MEETING REPORT

Authors: Brian C. O'Neill, Cecilia Conde, Kristie Ebi, Pierre Friedlingstein, Jan Fuglestvedt, Tomoko Hasegawa, Kasper Kok, Elmar Kriegler, Seth Monteith, Ramon Pichs-Madruga, Ben Preston, Jana Sillman, Bas van Ruijven, Detlef van Vuuren.

October 4, 2019

PARDEE.DU.EDU

UNIVERSITY of DENVER
JOSEF KORBEL SCHOOL OF INTERNATIONAL STUDIES

# Forum on Scenarios of Climate and Societal Futures

University of Denver, Denver, CO
March 11-13, 2019

## Scientific Steering Committee



## Acknowledgments

*The Scenarios Forum was generously supported by:*
The ClimateWorks Foundation
Office of Research and Sponsored Programs, University of Denver
Frederick S. Pardee Center for International Futures, University of Denver

*The Forum was kindly endorsed by:*
Intergovernmental Panel on Climate Change (IPCC)
International Committee on New Integrated Climate change assessment Scenarios (ICONICS)
World Climate Research Programme (WCRP)
Integrated Assessment Modeling Consortium (IAMC)

*The Forum was hosted by:*
Frederick S. Pardee Center for International Futures and Josef Korbel School of International Studies, University of Denver, Denver, CO.

*This report benefited greatly from the following contributions:*
Summaries of parallel sessions by session organizers (see Appendix V)
Summary thoughts by presenters in the final plenary (Jan Fuglestvedt, Paula Harrison, Elmar Kriegler, Julia Leininger, Bas van Ruijven)
Participants providing feedback to the final plenary and during the meeting

## Suggested Citation

O'Neill, B.C., Conde, C., Ebi, K., Friedlingstein, P., Fuglestvedt, J., Hasegawa, T., Kok, K., Kriegler, E., Monteith, S., Pichs-Madruga, R., Preston, B., Sillman, J., van Ruijven, B., van Vuuren, D. 2019. Forum on Scenarios of Climate and Societal Futures: Meeting Report. Pardee Center Working Paper 2019.10.04, University of Denver, Denver, CO. 107 pp.

# Contents


Background and goals ..... 5
Outline of the meeting ..... 6
Meeting outcomes ..... 7
Summary of parallel sessions ..... 7
Key highlights and notable advances facilitated by the framework ..... 7
Suggested improvements and extensions ..... 8
Planned follow up activities ..... 9
Summary of plenary sessions ..... 9
Summary of online final plenary ..... 12
Insights ..... 12
Challenges ..... 12
Conclusions and next steps ..... 13
Appendices ..... 14
Appendix I: List of participants ..... 14
Appendix II: Forum agenda ..... 17
Appendix III: Research gaps and needs ..... 21
Appendix IV: Summary of online final plenary and feedback ..... 24
Insights ..... 24
Challenges ..... 26
Next steps ..... 29
Appendix V: Session organizer questionnaire and feedback ..... 33
Questionnaire ..... 33
Biodiversity ..... 34
Communication ..... 36
Demographics ..... 37
Economic modeling ..... 40
Electrification ..... 42
Extremes ..... 44
Finance ..... 45
Geoengineering ..... 47
Governance ..... 49
Impact Costs ..... 51

Impacts - I ..... 53
Impacts - II ..... 55
Impressions ..... 57
Inequality ..... 61
Infrastructure ..... 64
IPCC AR6 ..... 65
Migration ..... 74
Multi-scale Scenarios ..... 76
Nitrogen ..... 78
Oceans ..... 81
Overshoot ..... 82
Regional climate ..... 84
Scenarios and assessment ..... 85
Scenarios as Service ..... 87
Short-lived Forcers ..... 88
SSP Extensions ..... 91
Subnational ..... 92
SDGs ..... 95
Taking Stock ..... 97
Tracking progress ..... 101
Transition dynamics ..... 102
Urban ..... 104

## Background and goals

The goal of the Scenarios Forum was to bring together a diverse set of communities who are using or developing scenarios for use in climate change and sustainability analysis to exchange experiences, ideas, and lessons learned; identify opportunities for synergies and collaboration; and identify knowledge gaps for future research.

By taking stock of progress and facilitating further scenario-related research, the meeting aimed to inform the use of scenarios in the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). It also sought to help ensure a research base sufficient to inform future national and international assessments as well as policy initiatives, including the Sustainable Development Goals (SDGs).

An important, but not exclusive, focus of the meeting was the ongoing process of developing and using the so-called “scenarios framework” for fostering integrated climate change and sustainability research. As part of that framework, climate models have simulated alternative climate outcomes driven by the Representative Concentration Pathways (RCPs), and a new set of societal futures, the Shared Socioeconomic Pathways (SSPs), has been developed and used by integrated assessment models to produce a first set of global energy, land use, and emissions scenarios based on them.

The community has begun working on the integration of these climate and societal futures to investigate climate change impacts as well as mitigation and adaptation response options. The rapidly expanding set of activities drawing on the SSP-RCP framework includes large-scale impact assessments of health, agriculture, water, and ecosystems, as well as region-specific assessments. A new round of scenario-based climate model simulations is underway, and the use of the SSPs is expanding beyond the climate change community to facilitate work on other aspects of global change.

The Forum addressed the critical need for researchers from various communities to come together to share their experiences, progress, and plans. It provided a means of promoting integration across the climate modeling, integrated assessment, and impacts, adaptation, and vulnerability communities, as well as with additional research communities in the social, natural, and sustainability sciences. It also aimed to improve linkages among the research, assessment, practitioner and policy communities.

The main body of this report provides relatively brief summaries of the outcomes of parallel sessions, plenary sessions, and a final session (held online) that discussed meeting outcomes. More detailed information is contained in a series of appendices that include the participants and agenda, more detailed reporting on the final online plenary and the parallel sessions, and a summary of research gaps and needs.

## Outline of the meeting

The Forum was organized primarily through a bottom-up approach, in order to best reflect current activity and interests in the community. A call for sessions was advertised widely nearly a year in advance of the meeting, with a set of candidate sessions (along with their organizers) selected from those submissions by the SSC. That list was used to support a call for abstracts. A final set of sessions and abstracts was selected through an interactive process involving both the SSC and session organizers. Plenary sessions were scheduled to address key meeting-wide issues including the role of scenarios in global assessment and frontier research topics.

Participation in the meeting was open, although a request process was set up to ensure that attendance did not exceed the capacity of the location. In total, there were more than 290 registered participants (Appendix I) from 41 countries, with a substantial number of additional local participants.

The meeting took place at the University of Denver over a 2.5-day period, with a tutorial on the SSP-RCP framework held the afternoon of the preceding day. The agenda (Appendix II) included an opening plenary session introducing the meeting and provided an overview of the current status of scenario frameworks and their use. It was followed by a second plenary on the use of scenarios in global assessments, including in the current IPCC assessment cycle. The remainder of the meeting included 36 parallel sessions on a wide range of topics. An additional plenary on day 2 featured talks on frontier topics in scenario-related research. A final plenary for synthesizing lessons learned and next steps did not take place due to inclement weather. However, a “virtual” version of the session was held by circulating by email the presentations that would have been given to initiate the final discussion, and collecting feedback from participants on the reflections offered there.

A number of steps were taken at and following the meeting to collect input from participants in order to inform meeting conclusions. Session organizers were asked to provide written summaries of key session outcomes (see Appendix V for the questionnaire and responses from each session). During the meeting, participants were requested to send thoughts on key takeaways to the SSC (via a central email address) to inform the final plenary discussion. The final plenary was initiated by brief presentations by five participants spanning a range of disciplines and communities. Those presentations offered different perspectives on key takeaways and possible next steps. The presentations were circulated to participants by email with a request for feedback and additional thoughts, and responses collected over a period of 2-3 weeks (see Appendix IV for highlights of presentations and a summary of feedback). The SSC drew on all these materials, in addition to their own experiences at the Forum, to produce this report.

# Meeting outcomes

## Summary of parallel sessions

Reports from session organizers were received from nearly all of the 33 total sessions. Common themes and highlights of responses are summarized briefly below, organized into three topics (key highlights/advance, suggested improvements/extensions, follow up activities) based on the 6 questions to which organizers responded. The questionnaire and full reports from sessions are included in Appendix V.

### Key highlights and notable advances facilitated by the framework

Session organizers generally concluded that the SSP-RCP framework is being widely used throughout the climate and sustainability research communities. It is also facilitating progress in communities not as frequently represented in the past, for example in the areas of climate finance, the nitrogen cycle, and oceans.

The conceptual framework has been largely successful so far at enabling kinds of work for which it was designed. Its framing that gives equal weight to facilitating research on impacts/adaptation and mitigation appears to be promoting a balance of studies on both issues, including those that integrate the two. It is also allowing for analysis of the co-evolution of climate and society, including the relative sensitivity of outcomes (particularly impacts) to climate and societal conditions, often finding that societal changes as represented by the SSPs outweigh the effects of climate change. Although the main elements of the framework are defined globally at the level of large world regions, it has facilitated research across scales, including in Europe, New Zealand, Japan and the US. In many cases this work has involved a variety of types of interaction with stakeholders. This regional experience suggests that the framework has successfully transitioned out of the integrated assessment modeling community and is finding traction in a broader, more diverse community of global change researchers and practitioners.

In addition to research, the framework is facilitating assessment by providing a literature base with common assumptions about future societal and climate conditions. It assisted in drawing conclusions in the IPCC Special Report on 1.5 C, was drawn on to support the assessment of the International Panel and Biodiversity and Ecosystem Services (IPBES), helped inform the US National Climate Assessment, and is currently playing a role in integration across IPCC working groups in the Sixth Assessment Report (AR6).

Sessions highlighted some features of the framework as helpful in particular ways. Narratives have been found to be a useful basis for extending the SSPs to provide additional information, for example regarding urbanization, migration, technological development, political trends, and poverty. Quantitative drivers such as population and GDP are being used widely, as are outcomes of IAM scenarios based on the SSPs, facilitated further by an open database of

quantitative SSP and scenario outcomes.[1] Extensions of the SSPs to spatial population, GDP, income distribution, and governance and conflict indicators, as well as regional elaboration, are also strengthening analyses particularly of future vulnerability and risks, and also beyond climate change to issues reflected in the Sustainable Development Goals (SDGs).

## Suggested improvements and extensions

At the same time, session participants identified a number of ways in which the SSP-RCP framework, and scenario work in general, could be improved. A detailed list of research gaps and needs is provided in Appendix III. It highlights several categories of improvements that would facilitate more and better work supported by scenarios. For example, a wide range of additional information that would add detail to SSPs or RCPs was thought to be useful, including information on domestic migration, urban conditions (city-level projections, governance, air pollution), materials use and supply, sectoral activity detail in narratives, additional near-term scenario detail (especially to support climate policy analysis), and further spatial downscaling of socio-economic indicators. Earth system model projections, especially regional downscaling, could be improved by accounting for SSP-specific land use changes. It may also be time to begin updating the quantitative elements of the SSPs (population and GDP projections in particular) to be consistent with more recent data, although such a step would involve tradeoffs with the desire for consistency in scenario assumptions across studies drawing on the SSPs.

Shared Policy Assumptions (SPAs), a component of the framework that facilitates analysis of adaptation and mitigation, were highlighted as having untapped potential and needing further development, especially for adaptation.

The framework could be usefully extended to capture scenarios not part of the current set. SSPs that represented low (or negative) economic growth, and greater regional heterogeneity, are two examples. Scenarios more amenable to geoengineering research would also be useful. Developing futures that better reflect non-Western perspectives and the views of activist communities could also be beneficial to widening the range of considerations. In addition, storylines that integrate research findings from across studies based on the same SSP-RCP scenarios would help draw synthetic conclusions from scenario research, and be useful in communication as well.

More broadly, the organization of the framework around questions central to the climate change issue (most notably, challenges to adaptation and mitigation) has facilitated progress in this area but was also seen as limiting the applicability of the framework to other topics. Biodiversity issues, for example, would be better served by broadening the framework to include determinants of biodiversity and to incorporate types of models prevalent in that field. Applications to analysis of the SDGs would be improved by expanding the content of the SSPs related to distributional issues, equity, and governance.

[1] https://tntcat.iiasa.ac.at/SspDb/.

Finally, there are substantial needs for more and better communication of the framework and guidance on its use, especially for regional applications.

### Planned follow up activities

Session participants noted a number of planned or desirable next steps in the scenarios process. Several products from the meeting itself are in preparation. A synthesis paper of broad meeting conclusions and proposed next steps is being produced, as are papers from several individual sessions that take stock of and propose future directions for specific scenario-related topics. A number of projects or activities that were already underway were advanced by Forum sessions, including a GTAP-sponsored project on baseline scenarios, an EMF study focused on Paris Agreement targets, World Bank infrastructure and migration reports, an FAO-hosted meeting SSP-based fishing sector scenarios, and model comparison projects on geoengineering (GeoMIP), fisheries (FishMIP), and regional climate (CORDEX).

## Summary of plenary sessions

The Forum included three plenary sessions (a fourth, the final plenary, was not held due to weather conditions). The opening plenary included context and plans for the meeting, as well as an overview talk by Kristie Ebi on the status of scenario frameworks in climate and sustainability research. It emphasized the critical role of scenarios in informing interdisciplinary research and assessment of the risks and opportunities of global environmental change, and of the potential cost-effectiveness of short- and longer-term policies and actions across spatial and temporal scales. There is an over 30-year history of creating such scenarios to provide internally consistent and comparable visions of possible futures as inputs into qualitative and quantitative projections of changes in hazards, exposures, vulnerability, and capacities over time, and of the possible effectiveness of adaptation and mitigation policies and measures. The Shared Socioeconomic Pathways (SSPs) include qualitative narratives and quantifications of a range of possible development pathways over this century that can be paired with compatible pathways of greenhouse gas concentrations (RCPs) and with policy assumptions to create the next generation of scenarios for research. Scenario analysis is more relevant than ever to inform, for example, implementation of the Paris Agreement, achievement of the UN Sustainable Development Goals, the Intergovernmental Panel on Climate Change 6$^{th}$ Assessment cycle, assessments of risks and opportunities for low-carbon and sustainability transformations, and risk management decisions by public and private actors. Between their first availability in 2015 and March 2019, more than 385 publications were published using two or more SSPs, across a wide range of impact sectors and mitigation policy evaluations.

A session on scenarios in global assessments featured a presentation from IPCC chair Hoesung Lee, remote presentations from co-chairs of each of the three IPCC Working Groups, and a presentation by Detlef van Vuuren on scenarios in other global assessments. Lee pointed out that 2019 is a critical year for the IPCC Sixth Assessment cycle. The First Order Drafts of all three WG assessments will be available and the remaining special reports and methodology report will be finalized this year. He reflected on ways that scenario-related scientific analysis can help the IPCC make its messages more meaningful and relevant to policy makers.

Research can address the disparity between the global cost-effective pathways used in the scenario community and the decisions by actors on national and local scales; the dynamics of mitigation costs arising from path-dependency, asset stranding, positive lock-in, and various externalities; and uncertainties our understanding of climate damages. Much of the work of the scenario community will be a key ingredient to the AR6.

Valérie Masson-Delmotte, co-chair of Working Group I, looked back at lessons learned from SR1.5, with an overview of remaining knowledge gaps. She emphasized the role of scenarios in the WGI report currently underway and how they could facilitate stronger integration between the three WGs. Masson-Delmotte also pointed to the cross Working Group team on scenarios that has been established in the 6th Assessment cycle (AR6), what it aims to achieve in terms of consistency on various key issues across chapters and reports, the potential for improved communication, as well as an element of integration for the Synthesis Report. She also addressed the challenges for science, assessment and policy in addressing interactions between climate change and biodiversity.

Hans Otto Pörtner, co-chair of Working Group II, described the risk framework and its use across IPCC working groups. It has been very influential, for example informing the Reasons for Concern approach in the AR5 Synthesis Report and SR1.5. It would be very useful if such central analyses with such powerful messaging to policymakers could be incorporated even more in scenario work. This would for example support the development of Climate Resilient Development Pathways. A dynamical consideration is needed of how adaptation reduces risk over time, for different systems, globally and locally. Pörtner encouraged the community to think further about how to improve on bringing central policy relevant processes into the scenario work and how to improve understanding of policymakers and their appreciation of associated messages.

Jim Skea, co-chair of Working Group III, focused on coherence and information flows related to scenarios within WG III, such as the bridge between the short/medium term (2030-50) and the long-term (2100), links to sectoral chapters (especially the “systems” chapters: energy, AFOLU), investment “needs”, mitigation potentials and costs, and scenario background and assumptions. He also addressed the links to the other WGs, which are probably more direct and scenario-based with WGI1 than with WGII. He also reflected on communication of scenario results and emphasized the importance of transparency. Skea ended his presentation by pointing to some substantive issues that the scenario community needs to address, including reducing global temperatures after 2050 through the large scale use of BECCS, the role and use of the AR6 scenarios database, and the use of discounting in IAMs and other models.

Detlef van Vuuren discussed the role of scenarios in other global assessments, including the biodiversity assessment IPBES (associated with the Convention on Biological Diversity), UNEP’s Global Environmental Outlook, the Global Land Outlook, and the Global Energy Assessment. A set of scenario archetypes can be identified that are common across these assessments (such as market optimism scenarios, reformed markets scenarios, sustainable development scenarios and regional competition). The SSPs can be mapped against these

archetypes, allowing for synthesis across the scenario literature. There are major advantages of building “shared scenarios” across different communities including joint learning, recycling of material, and the possibility to compare across different research domains (biodiversity and climate). The SSPs have strongly contributed to the emergence of such a community, in research projects as well as international assessments. While this allows these projects and assessments to profit from the above mentioned benefits, at the same time the use of similar scenarios across communities implies that they might not be fully targeted to the most relevant questions in that particular community. To some degree, this can be overcome by extending or reinterpreting the SSP storylines and matrices.

On day two a session on Frontiers in Scenario Research featured talks on the status and needs for scenario-related work on adaptation (Ben Preston), extreme events (Sonia Seneviratne) and poverty (Stephane Hallegatte). Preston pointed out that the use of scenarios in adaptation research has evolved over time across four “frontiers” (climate scenarios, adaptation policy scenarios, socio-economic scenarios, and societal transition scenarios), resulting in an increasingly rich representation of the complexities of societal responses to climate risk. A key need is for scenarios that go beyond stating the kind of adaptation actions that are assumed to occur, to scenarios that articulate the transitions by which adaptation outcomes are achieved. The SSPs are creating a useful basis for such transition scenarios, but many challenges remain, including how to provide sufficient socio-economic detail in scenarios to support the development of these transitions, and how to bridge to applications at the local level and for shorter time scales more relevant to decision makers. Attention also needs to be drawn to possible feedbacks between adaptation action and SSPs, and the role adaptation pathways could play in terms of transition between SSPs.

Seneviratne made clear that the representation of the impacts of climate extremes will strongly affect the realism of scenarios that integrate climate and societal change. Currently, impact models typically do not take into account climate extremes or underestimate their effects. In addition, the land use incorporated in scenarios will affect the occurrence and intensity of climate extremes in the simulations. There are also important feedback processes between climate extremes and the Earth system that can affect impact outcomes. For example heatwaves and droughts can adversely affect ecosystems, diminishing their ability to buffer the impacts of climate extremes. A possible way forward could be to use emulators to simulate and represent the variability of climate extremes in IAMs and impact models used in scenario-based research. This would be a new frontier for joint scenario development between IPCC WG1, WG2 and WG3.

Hallegate focused on the topic of risk assessment, arguing that assessment should go beyond the risk of asset losses to measure losses of well-being, an approach that better captures risks to the poor. He also emphasized the need to move beyond vulnerability to consider resilience, i.e., the ability of a community to cope with and recover from their losses. Socio-economic resilience requires considering more than just income or GDP; it depends on poverty levels and access to risk management tools. Poverty is often defined via consumption (power), but it is also related to inequality and sustainable development. To better inform risk and resilience

assessment, we need scenarios that reflect conditions such as social protection, financial inclusion, retirement funds, and health care access, particularly on sub-national scales, since factors like social protection are often based on community efforts. This calls for efforts towards people-oriented metrics and regional scenarios that are more granulated and detailed on social systems and vulnerabilities.

## Summary of online final plenary

As noted, the final plenary was not held at the Forum due to weather conditions. Instead, the set of synthesis presentations that were prepared to stimulate discussion at that session (by Elmar Kriegler, Jan Fuglestvedt, Paula Harrison, Julia Leininger, and Bas van Ruijven) was circulated to participants after the meeting and feedback collected electronically. Here, we summarize the presentations and discussion briefly, categorized as insights, challenges, and next steps. These reflections were based on the full content of the meeting, including parallel and plenary sessions, and therefore include some overlap with the summary of reports of those sessions above. Presentations are available on the meeting website (https://www.scenariosforum2019.com/), and a more detailed summary of the presentations and feedback is included in Appendix IV.

### Insights

SSPs have served well as a flexible backbone for extension, modification and application to a very wide range of research topics, and have also served assessment well. They have been successful in increasing the importance of socioeconomic determinants of climate-related issues. Narratives have played an important role in facilitating the extension of the framework to regions and to additional sectors. That said, there is a need to further extend the framework especially to provide outcomes that can better support regional and local scale analysis, and to provide more detail on outcomes related to human conditions and well-being.

Key critiques and tensions involve improving the extent to which stakeholder perspectives are reflected in the framework and its application (although recognizing the limitations of stakeholder views), expanding its linkage to development issues (particularly as reflected in SDGs), and coping with issues related to plausibility of framework elements (especially regarding particular SSP-RCP combinations).

### Challenges

Improving the use and applicability of the framework faces a number of challenges. Allowing for extensions, updates and additions will be important, but needs to be balanced with the coordinative role the framework plays, which depends on stability and standard scenarios. A versioning system that prioritizes updates to some elements may offer a way forward. There is a desire for representing additional plausible futures not included in the current set, and adding variants or new pathways while retaining the core framework will be an important task. Futures of interest include those representing eco-communalism, low growth, scenarios that integrate climate feedbacks, those that better capture disruptive innovation and, more broadly, that push the boundaries of what is considered feasible.

An expanding framework will present challenges for characterizing and communicating uncertainty, and for visualizing output. Impact assessment has rapidly adopted the framework but assessment that can fully take advantage of the opportunity to distinguish the implications of alternative development pathways for future risks is still evolving. As an example, progress is being made in using scenarios to better integrate assessment across IPCC working groups but much remains to be done. Moving beyond climate change to improve the use of the framework for other issues, including biodiversity and human development, will require a concerted effort to recast the framework along dimensions of more direct relevance to those issues.

## Conclusions and next steps

Moving forward, there is a need to build on the Forum's role in taking stock of the use of scenario frameworks with additional efforts to review experience, derive lessons and inform plans for modifications. Review papers from some sessions at the Forum are planned. Efforts should continue to broaden and deepen interdisciplinary involvement in the scenarios community, including especially greater participation of the futures studies field, physical scientists, and continuing expansion of the role of social scientists. ICONICS plans to play a role in fostering this interaction, through webinars and its email list.

Research, and funding to support it, is required to address a number of gaps and needs (Appendix III). These include efforts to extend and modify current scenario frameworks, develop new scenarios that are not currently well represented, and improve training and communication related to scenarios and their use. In addition, support targeted to the kind of interdisciplinary research that scenarios aim to support will be essential to substantially moving the field forward.

There is strong support to continue the Forum as a recurring event every 2-3 years. ICONICS has agreed to facilitate the identification of a host, and interested institutions can contact its co-chairs.

# Appendices

## Appendix I: List of participants

| | | | |
|---|---|---|---|
| Adam Hawkes | Carl-Friedrich Schleussner | Dominique van der Mensbrugghe | Hamid Zoraghein |
| Adrian Hayes | Carlo Brancucci | Edward "Ted" Parson | Hannah Helmke |
| Adrian Leip | Carlos Manuel Welsh Rodriguez | Elisabeth Gilmore | Hannah Liddy |
| Alan Di Vittorio | Carolina Grottera | Elizabeth Babcock | Haroon Kheshgi |
| Alan Haynie | Caroline Zimm | Elmar Kriegler | He Chen |
| Albano Rikani | Casey Cronin | Emilie Brown | Heleen van Soest |
| Aleh Cherp | Cecilia Conde | Emily Laidlaw | Hélène Benveniste |
| Alex de Sherbinin | Ching-Cheng Chang | Eric Kemp-Benedict | Henrik Carlsen |
| Alex Wong | Chris Dent | Erich Striessnig | Hermann Lotze-Campen |
| Amanda Palazzo | Chris Weber | Erika Freimuth | Hermine Mitter |
| André Francisco Pilon | Christian Otto | Erika L. Roesler | Hoesung Lee |
| Andrew Hudson | Christian Wilder Barreto Schuler | Eunice Ramos | Holly Metzler |
| Andrew Jones | Christina Bradatan | Eva Sinha | Hugo Hidalgo |
| Anna Braswell | Claire Copeland | Evelina Trutnevyte | HyeJin Kim |
| Anowar Hossen | Claudia Tebaldi | Fabio Sferra | Hyun Min Sung |
| Anton Orlov | Claudia Wolff | Forrest Lacey | Ian Hughes |
| Aradhana Yaduvanshi | Colette Wabnitz | Fouad Khan | Jacob Schewe |
| Arjuna Srinidhi | Constantin Ruhe | Franziska Piontek | James Edmonds |
| Athanasios Vafeidis | Cornelia Auer | Fred Lipschultz | James Glynn |
| Avery Cohn | Cullen Hendrix | Friederike Otto | James McFarland |
| Ayansina Ayanlade | Dale Rothman | Gabriela Colorado-Ruiz | James Ward |
| Azmal Hossan | Daniel Nyquist | Geoff Burt | Jan Fuglestvedt |
| Barbara Willaarts | Daniel Russo | George DeMartino | Jan Kuiper |
| Barry Hughes | David Blauvelt | Gerald Nelson | Jan Kwakkel |
| Bas van Ruijven | David Bohl | Gert-Jan Geraeds | Jan-Ludolf Merkens |
| Benjamin Preston | David Kanter | Giacomo Marangoni | Jana Sillmann |
| Benjamin Sleeter | David Wrathal | Gillian Foster | Jared Carbone |
| Bill Gutowski | Deborah Avant | Giovanni Melina | Jason Levin-Koopman |
| Brendan Mapes | Deborah Balk | Gokul Iyer | Jay Lemery |
| Brian O'Neill | Delavane Diaz | Guillaume Rohat | Jayasankar C B |
| Bryan Jones | Detlef van Vuuren | Haewon McJeon | Jeffrey Bielicki |
| Caitlin Murphy | Dipti Gupta | Hamdou Wane | Jeffrey Logan |

Jennie Rice
Jesse Reynolds
Jiesper Strandsbjerg Tristan Pedersen
Jing Gao
Joe Lane
Joe Walston
Joel Smith
Joeri Rogelj
Joern Birkmann
Joern Schmidt
Johannes Bednar
John Pinnegar
John Weyant
Jomy Joseph
Jonathan Lamontagne
Jonathan Moyer
Juan-Carlos Ciscar
Jude Herijadi Kurniawan
Judy Lawrence
Julia Leininger
Julie Rozenberg
Jun Wong
Jun'ya Takakura
Kamal Ahmed
Kaoru Kakinuma
Kaoru Tachiiri
Kari Hyytiäinen
Kari Hyytiainen
Kasper Kok
Kate Calvin
Kate Watkins
Katja Frieler
Katrina Woodhams
Katsumasa Tanaka
Kavya Kamepalli
Kayenat Kabir
Keigo Akimoto
Keith Miller
Kevin Rennert
Keywan Riahi
Kiyoshi Takahashi
Kristie Ebi
Lace Padilla
Landy Sanchez
László Pintér
Laura Canevari
Laurent Drouet
Lawson Brigham
Leiwen Jiang
Lena Reimann
Linda Mearns
Lint Barrage
Luke Bevan
Madan Sigdel
Malte Meinshausen
Maoyi Huang
Maria Grahn
Marianne Tronstad Lund
Mariia Belaia
Mariliis Lehtveer
Marina Andrijevic
Mariya Absar
Mark O'Malley
Mark Rounsevell
Masahiro Sugiyama
Matt Hauer
Matthew Binsted
Matthew Gidden
Matthias Garschagen
Matthias Weitzel
Melissa Bukovsky
Michael Moran
Michael Obersteiner
Michael Walsh
Mohamad Hejazi
Mona Reiss
Muhammad-Shahid Siddiqui
Muye Ru
Narasimha Rao
Neal Graham
Nicholas Cradock-Henry
Nick Martin
Nico Bauer
Nicolas Siorak
Nicole Aimone
Norman Kearney
Oliver Geden
Olivier Boucher
Oreane Edelenbosch
Paruthummootil Jacob Philip
Patricia Romero-Lankao
Patrick Keys
Paul Sutton
Paul Wolfram
Paula Harrison
Pauline Scheelbeek
Perrin Ireland
Peter Lawrence
Peter Marcotullio
Peter Riggs
Ralf Ludwig
Raya Muttarak
Raz Mason
Reinhard Mechler
Richard B. Rood
Richard Hanna
Rita Van Dingenen
Rob Alkemade
Rob Dellink
Robert Lempert
Robert Newell
Robert Nicholls
Roberto Schaffer
Rodrigo Leal
Samuel Sellers
Sandy Johnson
Sara C. Pryor
Sathaporn Monprapussorn
Sean Low
Seo Hyung Choi
Seth Monteith
Sha Yu
Sheila Kong Mukwele
Sherri Goodman
Shihhsun Hsu
Shilpa Rao
Shinichiro Fujimori
Shivika Mittal
Shouro Dasgupta
Sibel Eker
Silvina Alicia Solman
Simon Davidsson Kurland
Simon Nicholson
Simon Parkinson
Simona Pedde
Simone Tilmes
Soheil Shayegh
Sohel Firdos
Srinivasa Reddy Gollara Hatty
Steffen Lohrey
Stephane Hallegatte
Steve Arquitt
Steven Rose
Steven Smith

Sujeetha Selvakkumaran
Tami Bond
Taran Fæhn
Tereza Cavazos
Th Rita Lungnila
Timothy Carter
Tom Will
Tomi Lindroos
Tracy Kugler
Tyler Eddy
Vanessa Schweizer
Vivien Fisch-Romito
Wenchao Wu
Wilfran Moufouma-Okia
Wilfried Winiwarter
William Cheung
William Collins
Yashar Saghai
Yeora Chae
Yong Sebastian Nyam
Yoon-Jin Lim
Yuzhou Shen
Zbigniew Klimont

## Appendix II: Forum agenda

The full program, with all talks, speakers, and abstracts by session, is provided on the meeting website at https://www.scenariosforum2019.com/program. We provide a program by session name here.

**Sunday, March 10**

2:30 PM-4:00 PM Tutorial on the SSPs and scenarios framework

**Monday, March 11**

9:00 AM-10:15 AM Welcome and introduction
Brian O'Neill, University of Denver
Pardis Mahdavi, Acting Dean, Korbel School of International Studies, University of Denver
Corinne Lengsfeld, Vice Provost for Research and Graduate Education, University of Denver

Overview of status of SSP-RCP and other scenario frameworks
Kris Ebi, University of Washington

Goals of the Scenarios Forum
Brian O'Neill, University of Denver

10:45 AM-12:00 PM The role of scenarios in the Intergovernmental Panel on Climate Change (IPCC) and other global assessment
Hoesung Lee, Chair, IPCC
Valerie Masson-Delmotte, Hans-Otto Poertner, Jim Skea, IPCC Co-Chairs of Working Groups I, II, and III (all remote presentations)
Detlef van Vuuren, PBL

1:45 PM-3:30 PM Parallel sessions 1

SDGs-I Improving the SSPs to assess the Sustainable Development Goals - I
GOOD ENERGY SCENARIOS What is a “good” energy scenario (or not) for use in decision making for climate change mitigation?
HIGH END SCENARIOS Downscaling and enriching the RCP-SSP scenario framework as a basis for co-creating integrated and transformative solutions to high-end climate change
DEMOGRAPHICS Deconstructing demographic futures: population dynamics in the Shared-Socioeconomic Pathways
NITROGEN New nitrogen scenarios using the SSPs

SCENARIOS AND ASSESSMENT Scientific assessment of scenario-based research

4:00 PM-5:45 PM Parallel sessions 2

SDGS-II Improving the SSPs to assess the Sustainable Development Goals - II
SSPs IN ECONOMIC MODELS Shaping the SSP storylines in economy-wide models
OVERSHOOT Overshoot scenarios for Paris Agreement temperature targets: an interdisciplinary perspective
MIGRATION Climate-induced migration: applications and enhancements of the SSP framework
FINANCE Use of scenarios for assessing climate-related financial risk and opportunity
BIODIVERSITY Identifying and building on synergies across international scenario communities: examples from the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES)

6:15 PM-8:15 PM Conference dinner

Scenarios for National Security Decision Making: From the Cold War to the Climate Era
Sherri Goodman, Senior Fellow, Woodrow Wilson International Center

**Tuesday, March 12**

9:00 AM-10:30 AM Plenary: Frontier topics in scenario research

Adaptation
Ben Preston, RAND

Integrating changes in extreme events in scenario development
Sonia Seneviratne, ETH Zurich

Long-term scenario for resilience and risk assessments
Stephane Hallegatte, World Bank

11:00 AM-12:45 PM Parallel sessions 3

MULTISCALE-I Extending the SSPs across space and time: Multi-scale scenario development practices (Session I: Advances in methods development)

EXTREMES Scenarios for climate extremes and their socio-economic impacts
SCENARIOS AS SERVICE Using a scenario approach to reshape the debate on global infrastructure investment needs Scenarios as service
URBAN Urban futures under the new scenario framework
INFRASTRUCTURE Using a scenario approach to reshape the debate on global infrastructure investment needs
OCEANS Scenarios for the Future Ocean

2:30 PM-4:15 PM Parallel sessions 4

MULTISCALE-II Extending the SSPs across space and time: Multi-scale scenario development practice (Session II: Exploring geographic contexts)
GEOENGINERING Being Cognizant of the Framing of Solar Geoengineering in Scenario Design
IMPACT COSTS Cost of climate change impact and the use of scenarios
SCENARIOS IN IPCC Use of scenarios in IPCC's 6th assessment cycle (AR6)
TRANSITION DYNAMICS Socio-technical transition dynamics in scenarios for climate change mitigation and sustainable development: where next?
INEQUALITY Inequality and poverty, projections and distributional consequences for climate

4:45 PM-6:30 PM Parallel sessions 5

IMPACTS-I Use of the SSP-RCP scenario framework in climate impact analysis, including avoided impacts - I
REGIONAL CLIMATE Climate change scenarios in CORDEX domains
TRACKING PROGRESS Scenarios for tracking progress in international climate policy
TAKING STOCK Developing the SSPs: Taking Stock of Successes, Areas to Improve for the Future
GOVERNANCE Socio-economic futures and governance scenarios
SUBNATIONAL Sub-national scenarios for integrated modeling and analyses

6:45 PM-8:45 PM Reception and poster session

**Wednesday, March 13**

9:00 AM-10:45 AM Parallel sessions 6

| | |
|---|---|
| | IMPACTS-II Use of the SSP-RCP scenario framework in climate impact analysis, including avoided impacts (Part II: Water and land)<br>VULNERABILITY Scenarios for assessing human vulnerability to extreme events and climate change at the local and regional level<br>COMMUNICATION Scenario communication, co-production and visualization<br>SHORT-LIVED FORCERS The role of short-lived climate forcers in future scenarios<br>ELECTRIFICATION Renewable-based electrification: how can we improve scenarios for clean energy transition?<br>SSP EXTENSIONS Extending the Shared Socioeconomic Pathways for Impacts, Adaptation, and Vulnerability research |
| 11:15 AM-12:45 PM | Plenary: Key meeting outcomes, plans for next steps in the scenario process |

Forum adjourned

## Appendix III: Research gaps and needs

The following list of research gaps and needs for further work was synthesized from the session summaries in Appendix V.

Types of scenario-based research that need further improvement

- Extreme events in impact assessment; can scenarios better facilitate this kind of work, for example with more suitable climate information and better information on adaptive capacity?
- Better descriptions of how downscaling exercises are carried out. Many studies do not explicitly describe how they interpret the narratives and/or specific narrative elements to produce downscaled projections. In order to be able to compare downscaling exercises with each other, describing in detail the step from narrative to quantification is crucial.
- How best to estimate impacts of climate change on international migration within the SSP-RCP framework. International migration is included in the national population projections corresponding to each SSP; it is necessary to develop best practices.
- How best to assess SSP-RCP based literature. There may not yet be a critical mass of SSP-RCP scholarship that lends itself to being identifiable through machine learning, and automated literature retrieval approaches may not be able to distinguish SSP-RCP literature from broader climate change research.
- Model comparisons and evaluation of social science models
    - Development of economic model-based indicators to judge plausibility
    - More comprehensive hindcasting

Training and guidelines

- Guidelines on sub-global assessments. For example, a website, portal or database where sub-global assessments can upload their method/process, narratives and quantifications to enable learning and capacity building in the community.
- Guidelines on how to develop regional or sectoral extensions.

Additional information or detail within existing SSP-RCP framework

- Internal migration (narratives and quantification), and spatially explicit migration
- Income distribution, including better integration into storylines
- Further downscaling of metrics to characterize vulnerability and adaptive capacity to a wide range of climate impacts, including age structure, education, HDI.
- Urban information
    - Types of urbanization
    - Extension of the SSPs' narratives for urban-related topics (urban morphologies, spatial development, urban governance, slums development, urban inequalities, mobility, digitization, electrification of mobility, etc.)
    - Quantitative information at the city-level (e.g. population counts, demographic characteristics of urban dwellers, etc.)
    - Urban air pollution and heat island effects
- Additional information on elements of socio-technical transition dynamics, including a wider array of technological considerations (AI, nanotechnology, biotechnology)

- Labor supply and occupational changes
- Sectoral activity projections or narratives (especially helpful to CGE scenarios)
- Detailed electricity end-use technology cost, performance, and hourly demand profile data
- Narratives from national and local governments around industrial and regulatory development
- The role of carbon storage in long-term scenarios
- Materials use and supply
- More consideration of interactions between land-based and ocean activities
- A wider range of and more links between timescales covered by scenarios, especially relevant to climate mitigation policy
    - Link more detailed near-term scenarios with long-term transitions, including to at least until 2300, to clarify the implications of near-term decisions for longer term and at times irreversible impacts.
    - Scenarios that better link peak warming in the nearer term with longer term target warming levels
- Implications for biodiversity and conservation, especially at regional level
- Earth system information
    - ESM simulations with explicit energy crops due to differential effect on climate
    - Regionally downscaled climate information from RCPs using SSP scenarios (eg for land use)
    - Improved coverage of SLCFs. Several IAMs include BC, but PM2.5 (relevant for health) is not explicitly included. Also the costs of air pollution control is often not included.
- Further development of SPAs
    - Especially for adaptation, and at regional and local scales
    - Especially important for infrastructure investment needs (policy choices and variables related to governance)
    - How to separate impacts from autonomous adaptation from SPAs
- Integrated scenarios or storylines combining SSPs and climate change
    - Incorporate two-way feedbacks between society and climate; e.g. demography

Improved interactions among research communities and the policy community

- More demographers and demographic institutions involved in the process
- IAM and ESM interactions, e.g. on geoengineering
- Improved interaction with biodiversity community
- Further engagement on policy and political processes in a scenario-based way, exploring both what is still possible and what is not.
- Engage with defense and security communities, which have extensive scenario experience
- Improved interaction with political science communities, in particular research on political change, governance and violent conflict
- Further integration of researchers from the Global South
- Strengthen exchange with policy communities from Global South beyond UN

Additional types of societal pathways or integrated scenarios not represented in SSPs

- Generally encourage variation beyond SSP-RCP framework
- A regional split in which the rich countries go ‘green’ and developing countries continue to develop in conventional ways
- Solar geoengineering scenarios (both narratives and quantification), starting with SSP5-3.4-OS
- Overshoot scenarios with different length and magnitude, not represented by SSP5-3.4-OS, including those that extend beyond 2100
- Pathways with more regional heterogeneity in development
- Scenarios that integrate governance, conflict, and fundamental political change
- An SSP1 variant with less economic growth or degrowth in high income countries
- Testing whether existing SSPs are too centered on Western perspectives
- Additional SSPs, or information for existing SSPs, reflecting a wider range of biodiversity-relevant drivers within the global storylines/scenarios
- A move away from a climate-centric approach (mitigation/adaptation challenges) to a broader framing to incorporate additional communities, eg biodiversity, nitrogen, sub-national multi-stressor frameworks, etc.
- Variants of migration assumptions
- Scenarios that would imply low nitrogen use, since all SSPs currently imply high nitrogen
- National mitigation scenarios that consider political economy, jobs, etc.

Improved communication

- Better information on how SSPs were constructed
- Continued and expanded open availability of scenario data
- Storylines communicating the results of integrated scenarios (SSP-RCP combinations)
- Communication of the plausibility of the SSP and other scenario projections when they exclude environmental feedbacks. Such projections play a role methodologically, but need to be communicated carefully. Outcomes that do include feedbacks should be communicated as well.

Scenario development approaches

- Developing scenarios based on surveys of the existing scenario literature
- Explore scenarios development methods such as morphological fields (with different drivers and states) and cross-impact balance

## Appendix IV: Summary of online final plenary and feedback

For the final plenary, Elmar Kriegler prepared a presentation summarizing a preliminary set of insights from the Forum, and a four-member panel (Jan Fuglestvedt, Paula Harrison Julia Leininger, and Bas van Ruijven) put together presentations on next steps for the scenarios community. The summary below is organized by main topics contained in those presentations, and contains a brief description of statements in the presentations followed (in italics) by subsequent feedback. Not all statements generated feedback. Note that some content from panel statements has been integrated into the Insights and Challenges sections below.

### Insights

#### Scenario framework(s) are being broadly applied

SSPs have served well as a flexible backbone for extension, modification and application to a very wide range of research topics, and have served assessment well. They have been successful in increasing the importance of socioeconomic determinants of climate-related issues.

- *It is important to gather empirical evidence on how SSP-RCPs and other scenarios are used in practice, how the intended users understand and interpret them, because in this way we could find out what we can do better. Co-design alone cannot guarantee that everything will work out.*
- *Suggested research needed:*
    - *An overview of existing empirical evidence on how scenarios/model outputs are in reality used and interpreted by the intended users. The evidence could range from literature on empirical tests of how visualisations are perceived to more fundamental questions of large scenario ensembles vs. several scenarios and storylines.*
    - *Collaborative projects in which systematic evidence could be gathered for SSP-RCPs/model outputs.*

#### Bridging to social sciences has already begun

Modeling the transformation to sustainability requires more transdisciplinary research and engaging social sciences. It became evident during the Scenarios Forum that we are not at the beginning: (1) Social sciences (in particular political science and economics) show increasing interest in modelling conflict scenarios and predicting political change. Models are based on quantifiable indicators for governance and conflict. (2) Beyond that, social scientists have started to extend the SSPs with indicators for governance and conflict. Bridges between social sciences and modelers of future scenarios are there but they are still small, not very solid and not frequently used.

#### Narratives play a central role

Narratives have been a useful element of the framework in bridging scales, establishing basic consistency, co designing scenarios with users, and communicating scenario insights.

### Set of key socio-economic drivers needs to be extended

Extending the set of drivers would provide for better coverage of socio economic dimensions of scenarios. However, new extensions may suggest changes to the narratives.

### Granularity and output metrics matter for usefulness of scenarios

Scenarios are more useful when they are regionally specific and people-centered.

### Critiques and tensions

Key critiques and tensions related to the use of scenarios include: (1) The SSPs do not reflect sufficiently stakeholder perspectives from across the world. Broader stakeholder involvement is needed. (2) More work is needed to link SSPs to development issues, even though a lot of such is ongoing. (3) There are different perspectives on how plausibility considerations shape the SSP framework.

Stakeholder involvement

- *The methods used in recent studies are not always the best available, sometimes involving a small number of 'stakeholders' that may or may not understand the SSPs, the study goals and objectives or properly represent the core decision makers or the people who may be affected the most by lack of climate change adaptation. The community should communicate with the technology foresight/futures studies community about tried and tested methodologies and expertise in involving stakeholders to inform bottom up scenarios and storylines.*
- *Stakeholders should include academic scientists. If focused on the views of stakeholders scenarios will often be rather conservative and not very aspirational. The current scenarios adopted for energy in the SSPs or RCPs are already being shown to be too conservative in terms of energy transitions even over the last decade.*

Links to development issues

- *The use of the SDGs frame will be useful, although indeed the practicalities associated with using SDGs as a frame could also itself be the theme for a 'Scenarios 2020' conference.*
- *Scenario developers must make it clear to policy makers that the assumed value for the discount rate in economic optimization studies may, in fact, be the most important assumption of the entire study! Perhaps each scenario should have its own discount rate assumption that reflects the overall philosophy of that scenario. For example, perhaps SSP1 should have a 0% real discount rate reflecting its desire to mitigate sooner and deeper.*

Plausibility

- *It would be very important to clarify what SSP-RCP combinations are regarded as credible and which ones not, because many IAV studies appear to be adopting implausible pairs. Those providing the greatest confusion are RCP2.6-SSP5 and RCP8.5-SSP3. The former case is reported from simulations with IAMs to be feasible only at high cost in Riahi et al., 2017 (Fig. 8). The latter case, heavily represented in many studies, is regarded as implausible according to the baseline runs reported in Riahi et al., 2017 (Fig. 8).*

- *Working at regional and local scales, there is a clear challenge to apply RCP-SSP combinations in a manner that respects the underlying logic of the scenarios framework. Notwithstanding the many examples we have seen at the Forum of regional/local-scale, sector-based SSP development, it is somewhat surprising how few of these are explicit about the rationale for selection of the RCP-SSP combinations and the interpretation given to these.*

## Challenges

### Stable vs evolving framework

An open framework needs to allow for extensions, updates and additions. A coordinative framework needs to offer stability and standard scenarios. To combine the two requirements, we need versioning of updates for standard scenario elements (narratives at the core should be revised less frequently than drivers, and drivers less frequently than model quantifications. We also should allow simultaneous existence of standards on the one hand and continued extensions and additions on the other hand.

### Exploration vs shaping societal perceptions

Exploring alternative futures is a core function of scenarios map making. At the same time, scenarios shape societal perceptions and deliberations. Possible remedies include (1) user-oriented scenario exploration and co-production of narratives; (2) statistical methods that enable broader and more systematic scenario exploration (but need to retain the ability to filter out inconsistent scenario configurations); (3) responsible communication of scenarios that is reflective of their discourse-shaping implications.

### Capturing additional plausible futures

Additional futures could include:

- Sustainability scenario without high growth in income
- Regional sustainability paradigm (Eco communalism)
- SDG scenarios
- AI-driven scenarios
- Disruptive innovation scenarios, e.g. concerning energy efficiency
- High vulnerability/high climate change SSP RCP combination
- Shock scenarios, e.g. global instability and tipping points
- De-growth scenarios

- *Actor-explicit scenarios. SSP-RCPs and most energy models or IAMs do not have explicit representations of the actors and in this way gloss over the implications of the actors' decisions and the key levers of change.*
- *Scenarios that vary in coastal development. They would have differing impacts on the oceans at local and regional scales.*

- *SSP1 variant of Eco-communalism could be useful, especially since the Trump administration is trying to pull the US out of the Paris Agreement, while US cities and states are trying to stay the course.*
- *A de-growth scenario might also be useful for some contexts (but a complete non-starter in other contexts like the US for instance).*
- *We support the call for a SSP1 variant that deepens sustainability without high corresponding growth [in GDP/per capita incomes]. It might be thought of as a variant of SSP1 but also a scenario counter-posed to SSP3: a different set of assumptions re: human connections and the arc of justice not limited to a reduction in material through-put in de-growth scenarios. Currently the SSPs suggest that sustainability and growth are inextricably linked, but we would contest that notion.*
- *Integrated scenarios, with climate feedbacks. It would be important to see studies that try to answer the question about feedbacks from the impacted society on climate forcing/climate change and back to society more explicitly, systematically, robustly. Recognizing the argument that we do not want to "build in" the answer about impacts, there don't seem to be good examples of "derived answers" either. It may also be a way to better engage the WG1 type of community.*
- *"Hybrid" or "evolving" SSPs that start in a corner and end up in a different one over the decades of the 21st century.*
- *Scenarios that push the boundaries of what is "plausible". This is one compelling reason to enrich the current scenarios framework.*
- *Scenarios that deepen and sharpen work that uses 2050 as the 'end-point'. This is particularly clear in light of the fact that the IPCC indicated in their S.R. on the 1.5°C goal the urgency of substantial mitigation actions by 2030; and in the oft-stated concern of scientists that policy-makers and financial players find little utility in scenarios that spin out to 2100, far beyond any reasonable planning or policy horizon.*
- *Scenarios with downscaling efforts that address 'implementation barriers, speed/cost of implementation, and sustainability' in the context of different CDR approaches.*

### Assessing scenario uncertainty

Scenarios are developed to describe alternative futures in situations of deep uncertainty. Still users and stakeholders often ask to put a likelihood on narratives and associated projections. Several non-probabilistic approaches are being used and further developed.

### Communicating the scenario context, uncertainty, and visualizing output

These topics present a set of challenges for scenario users and providers, including understanding and explaining underlying scenario contexts, communication of uncertainty, and designing arresting visualizations of multidimensional output spaces.

### Scenario-based impact assessment

Scenario-based research is showing that climate change impacts on societies depend as much on socio economic developments as on climate change. It also demonstrates that there is significant adoption of SSPs by the impact community, but it remains a challenge how this work

can be assessed (e.g. RFCs). In addition, multi-dimensional climate risk assessment could be improved though more people-centered socio-economic information, improved extreme event statistics, and comparability across impact categories.

- *It may be correct that climate change impacts on societies depend as much on socio-economic developments as on climate change, but it is only true for some time horizons and some locations.*
- *Some places of the world do not have the luxury of considering their impact futures under the parallel process model, as their current status (and/or values) is based on climatic + socio-economic history. For such places, considering climatic + socio-economic dimensions separately would not make sense. Local analyses in such contexts should be sensitive to this. However, I would caution against abandoning the parallel process altogether. The parallel process has already spawned valuable research designs and may continue to uncover more.*
- *The quantified SSP variables in the SSP-RCP architecture are quite robust in the sense that even if climate change and societal response to climate change may have an effect on them, that won't affect their values very much since they each have so much 'momentum'. The climate change effects are more likely to impact the 'qualitative' aspects of these variables (e.g. on the distribution of GDP per capita throughout the population, or on the form of urbanisation (including allegedly 'ineffable' qualities of urban life such as 'ambience' and 'sense of place')). In other words, the SSP storyline can vary from the archetype when investigating specific empirical cases while the pattern of the quantified SSP variables might remain close to the reference ('marker') case.*

### Consistent scenario use across IPCC AR6

Scenarios are an integrating element across reports (Special Reports, Working Group reports) and can play an essential role for real synthesis in the Synthesis Report (i.e., not a summary of SPMs). However there are challenges with using scenarios in AR6: Comparing across models, studies, and regions; choosing scenarios; collecting information. Some views are that the IPCC cross-WG scenarios group is not pushing the integration effort strongly enough. More efforts are needed in communication of results from the RCP SSP framework. Openness of data is essential to allow new communities tap into this resource before and during the assessment process. An expert meeting at the end of the Sixth Assessment Report cycle could systematically feed back experience from AR6 process to the scenario community.

### Application of SSP-RCP framework to other global change issues

While the scenarios framework is being applied in some cases to issues beyond climate change, the framework remains climate-centric. It would broaden its usefulness to recast the axes defining SSPs into drivers that are not so climate-centric to open it to other assessments, which could then extend them to match their needs. To this end, dialogue is urgently needed between ICONICS and the IPBES Task Force on Scenarios and Models, as they will soon make a decision on whether to develop new scenarios (Nature's Visions) or link to the RCP-SSP framework. New scenarios would detract from comparability across the assessments, for

example between IPBES and IPCC. It could be argued that IPCC has a moral obligation to interact and support younger and less experienced assessment through collaboration and integration.

- *IPCC has really been the innovator with respect to environmental scenarios, and I agree that this wisdom/capacity should be shared as much as possible.*
- *I think it would be good to have IPBES and a Social Sciences society as 'partners' somehow as well. These connections from the inaugural Forum should not be lost.*
- *If the climate change research community wants to support these other uses then I think the inevitable modifications to the core SSPs required should be approached as 'extensions'. In the case of use by other research communities, one can visualise the conventional SSP-RCP matrix being modified so that the rows represent variation in Variable Y (e.g. level of governance), and the columns remain as the SSPs. One can imagine this approach will be fruitful in some cases and not others.*

## Next steps

### More systematic stock-taking and assessment of experience with scenario framework

Additional efforts to draw lessons from the many studies using SSPs would be valuable. Ideas include:

· An interactive structured process to collect feedback from regional/sectoral extensions and assess the salience of SSPs to stakeholders.

· A review/assessment paper on the wide range of approaches to bridging scales

· A portal/database (i.e. an extension of the IIASA database) to allow researchers to upload information on their process, resulting narratives and quantifications

· Better understand the comparability of results as studies often use different quantifications of the same narratives for different location/scale contexts

· Test whether the global framework is relevant in non-Western contexts (as it has mainly come from a Western science worldview). Further development should seek to incorporate a wider range of worldviews and values.

- *There is strong support for the need for a database where researchers can upload information on SSP extensions applied in their studies. This needs to be structured, though, so potential users can navigate it in a logical manner.*

### Continue strengthening links across communities involved in developing and using scenarios

While the Forum contributed to strengthening interactions among communities, continuing efforts should be made to broaden and deepen these connections. This should include communities across the climate change field, but also to other fields involved in global change issues. It should also include further engagement of the natural sciences, social sciences, and humanities.

For example, the social science community is often not aware that there is a place for them in the “world of future scenarios”. Integrating empirical findings from social science research into future scenarios gives social sciences an opportunity to contribute to the “big picture”. In addition, concept-building is often more important in social than in natural sciences, and therefore more time is needed to reach common ground

There is a need for a practice of collaboration and cooperation in joint work streams and projects. Links can be strengthened via existing conferences, targeted new meetings, joint research projects. Only if the different communities, disciplines and sciences get an opportunity to work together will they be able to integrate their agendas and research. In order to facilitate and foster joint research projects, we need to address funders and editors to set incentives.

ICONICS in particular proposes to foster continued dialogue among communities. Key activities that it proposes to facilitate include:

- Systematic stock-take and feedback on the Scenarios Process
- Develop a versioning system for SSPs and quantifications
- Collection and dissemination of additional indicators for the SSPs

It also proposes to facilitate building a knowledge base:

- Using the SSPs in stakeholder engagement projects
- Communication of the SSPs
- Assessing scenario uncertainty

And in addition to facilitate key discussions:

- Tension between open and coordinative framework
- Plausibility: concept, definitions, considerations
- Broadening the perspective of worldviews represented in the SSPs

Depending on interest from the community, this ‘facilitation’ has many potential forms: email-list discussions, co-organize workshops, coordinated papers, etc

- *The continued dominance of the quantitative modeling community remains an issue. We made a step forward in developing the SSP narratives, but they were still primarily written by people from a quantitative and modeling background.*
- *Greater interaction with the technology foresight/futures studies community. As we move forward with the SSPs framework, there is merit in bringing in other well established disciplines to help us generate more comprehensive knowledge for future planning and assessment.*
- *More extensive involvement of physical scientists. There are geotechnical limits to scenarios and engineering solutions but these aspects were played down in these slides.*
- *For the whole community, funding interdisciplinary scenario-based research is a key to moving forward, unless we are going to rely on next steps being performed by a coalition of the willing.*

### Develop guidance material and activities on scenarios frameworks and their use

A guidance document and other materials on alternative approaches for developing and applying the RCP-SSP-SPA framework would foster improved understanding and wider use (especially beyond developed country settings). Materials could include:

- A compilation of existing approaches to RCP-SSP scenario development and application and guidance for future studies based on experiences to date
- A classification of the methods employed, including their main advantages and drawbacks for different applications, including their resource considerations (time, personnel, funds)
- Case studies of scenario application
- Guidance on the use of a single (e.g. SSP2) vs multiple SSPs for capturing a range of outcomes and ensuring greater robustness of adaptation and/or mitigation decisions

### Updating, modifying or further developing the scenario framework

In the near future updates or modifications to the scenarios framework may be advisable, particularly to SSP quantitative elements to be more consistent with recent data, but also potentially with other elements and the framework. Some terminology has also presented challenges and changes could be considered. The name of SSP5 (fossil-fueled development) has been an obstacle for presenting outcomes to stakeholders. There have also been issues with the term “pathways” in local/regional studies as it is confusing when combined with the development of adaptation pathways.

Further development of Shared Policy Assumptions (SPAs) would be valuable. There is little work on SPAs in local/regional applications, particularly with respect to adaptation. Regionalised SPAs or time-dependent SPAs would be interesting to explore.

- *The SSP-RCP architecture was designed to be fit-for-purpose at a particular time. It will lose its integrating function within the research community if it is constantly revised and updated, but changing circumstances will require some modifications over time. The suggestion that it could go through a limited number of ‘official’ versions over the coming years seems like a sensible compromise. Version 2 could perhaps be designed specifically to help those in the research community who want to answer the research questions that arise when you assess the results of AR6 in the context of the SDGs.*
- *I'm a bit confused by the suggestion that SSPs and SPAs are not time dependent, since I perceive that they are.*
- *The lack of attention paid to SPAs, which are actually essential elements of scenarios adopted in studies that apply RCP-SSP combinations, is clearly evident. If they are not being avoided, then SPAs are being treated in an ad hoc manner as an add-on to the RCP-SSP basic scenarios. I would suggest that there is still some methodological development needed to address this element. It may be useful to review the existing literature to see if some of the results that are reported in other terms are actually describing SPAs, and also to consider if the scenario framework itself needs some refinement to recognise alternative, scale-dependent interpretations of SPAs.*

## The next Scenarios Forum

There is a tentative plan to continue the Forum as a recurring event every 2-3 years, with ICONICS facilitating the identification of a host. ICONICS also proposes to keep the structure the same, as a Forum presented by ICONICS in partnership with the IAMC and WCRP.

- *There is strong support for continuing the Scenarios Forum on about a 2 (or 3) year time frame.*
- *One possible timing would be early 2021, before cut-off dates for paper submission for inclusion in the WG2 and WG3 reports in the IPCC AR6. Tying it too closely to the AR6, though, might reinforce the concern that the SSP-RCP framework is too climate-centric.*
- *Having ICONICS present this in partnership with only the IAMC and WCRP seems problematic, unless ICONICS really works to become more inclusive of the broader scenarios/futures community.*

## Appendix V: Session organizer questionnaire and feedback

### Questionnaire

The following questionnaire was sent to all session organizers as a suggested guide to providing feedback on key outcomes from their sessions.

**Scenarios Forum Session Organizer Feedback**

Please summarize highlights of your session at the Scenarios Forum. You should include whatever content you feel is most important to communicate the results of the session, but we ask that at a minimum you address the questions below. We envision your response to be about 2 pages in length.
These session summaries are intended to capture outcomes, insights, and progress made at the Forum and will be included as an annex to the Meeting Report. They will also be used to help provide a higher level overview of meeting outcomes in the Meeting Report, which will be written by the Scientific Steering Committee, possibly with additional meeting participants. Any use of the content of session summaries for the Meeting Report or a synthesis paper on the status and outlook of the scenario process will be properly credited.

**Session name**:

**Session organizer(s)**:

What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?

What features[2] of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?

What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?

What are other key highlights from your session?

What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?

[2] By “features” we mean elements like narratives, quantitative drivers, or IAM scenarios, or aspects of the framework like the matrix approach to combining socioeconomic and climate information, or the spanning of uncertainty in challenges to adaptation/mitigation.

What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?

## Biodiversity

Session name: Identifying and building on synergies across international scenario communities: examples from the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES)

Organizers: Mark Rounsevell (Karlsruhe Institute of Technology)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

- The SSPs formed part of the scenario archetypes that were developed and applied in the IPBES regional assessments. This was an extention of the van Vuuren archetypes with an additional inequality archetype that reflects SSP4.
- IPBES is exploring how to develop its own approach to scenarios known as 'Nature's futures'. This approach might embed the SSPs within a framework on how nature is perceived, e.g. 'nature for nature', 'nature for people' and 'nature for culture'. In this context the SSPs could form variants of the 3 'nature' scenarios.
- Outside the IPBES framework, Sanderson et al. showed an example of how the spatially-explicit population projections based on the SSPs (Jones and O'Neill 2016) can be used to inform biodiversity conservation more generally, and tiger (Panthera tigris) conservation specifically.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

- The SSPs (naturally) have a climate change focus; there is a lack of representation of drivers that are relevant to drivers of biodiversity and ecosystem services change, e.g. invasive alien species, natural resource extraction, pollution. Though clearly the population/urbanization, and to lesser extent, economic projections, are useful in the context of biodiversity conservation.
- Furthermore, much of the quantification of the SSPs has been undertaken by IAMs, which are not often adapted to biodiversity questions (with some exceptions, e.g. GLOBIO/IMAGE)
- Generally the literature is dominated by climate change questions, which biases assessments (such as IPBES) that are exploring a wider range of drivers.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

- Learning from other (non climate change) communities to develop more broadly applicable scenario frameworks
- Incorporating a wider range of biodiversity-relevant drivers within the global storylines/scenarios; and guidelines (or information from other sectoral extensions of the

SSPs) on how they could be made more relevant for biodiversity and ecosystem services at a range of scales.

- Expanding the framework with local or regional oriented scenarios, such as local sustainability scenarios to address a broader range of biodiversity relevant policies, including adaptation strategies.
- Moving away from the climate-centric perspective (mitigation/adaptation challenges), since this gives a disproportionate weight to climate change as a driver rather at the expense of other important drivers.
- Scenarios of demography and urbanisation (i.e. where do people live) and how these translate into consumption scenarios are critical in better understanding the consequences for nature conservation, especially of large predators and likely many other species
- Better quantification of the impacts of land-based mitigation scenarios (e.g. BECCS, afforestation/reforestation) on biodiversity and the provision of ecosystem services.
- Biodiversity is a sub-global phenomenon, so more regional representation of SSP storylines would be helpful.

*What are other key highlights from your session?*

- There is a structural problem within the IPCC WGs that separates adaptation and mitigation scenarios.
- IPBES and IPCC should have started a dialogue earlier, but should certainly now continue to discuss common approaches to scenario development/modification
- It is important to note that a process to generate more biodiversity relevant "visions"/scenarios/archetypes is well underway under IPBES, but largely outside and unaligned with the SSP framework. There were some questions raised during the session about whether new biodiversity scenarios are truly necessary, given the extent of work already conducted with the SSPs, even if the SSPs do not include all the desirable aspects/storylines (as noted above)
- IPCC has a moral obligation to raise awareness of other (non-climate change related) environment issues within scenarios
- A number of key questions for scenarios of socio-ecological systems have been identified, including:
    - How can scenarios better integrate cross-scale interactions and teleconnections?
    - How can scenarios produced at different scales be used to complement those produced at another?
    - What methods can be used to transparently, efficiently, and productively combine co-produced narrative storylines with technical quantitative models?
    - What are the strengths and weaknesses of different methods to stimulate and incorporate non-linear thinking in scenarios?
    - How can conflict or tensions between multiple values and worldviews be usefully incorporated in scenario logic and narratives?
    - What are effective strategies that help ensure that participants integrate scenario outcomes into daily practice?

- How can the longer term impacts of scenario planning processes be measured and documented? What's the best way to organize the monitoring, impact evaluation and assessment of the scenario process?
- What approaches, methods and tools of scenario analysis work best to produce specific types of outcomes in different social-ecological-technological contexts?
- How can scenarios be used to initiate and navigate transformations of the global economic and social system towards sustainability?

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

- National governments/decision-makers through IPBES and IPCC processes
- The IPCC and IPBES research/assessment communities
- The CBD post-2020 process
- Nature conservation practitioners

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

- Continued reflection and implementation of the IPBES 'Nature's futures' through the IPBES task force on scenarios and models (R. Alkemade)
- Publication of the IPBES archetypes
- Publication of a research agenda on social-ecological scenarios
- Further investigations of the implications of the SSPs for wildlife species / conservation

## Communication

Session title: Scenario communication, co-production and visualization

Session organizer(s): Kasper Kok (University of Wageningen), Elmar Kriegler (PIK)

The interest in the session showed that there is a great need for advanced communication of scenario content. As the amount and diversity of available scenarios continues to increase, the question of how to communicate and visualize tailor-made (co-produced) useful subsets has become crucial. Scenario visualization also plays a role for scientific innovation as visual information not only allows to transmit dense information but also to reveal causalities and inconsistencies.

The session covered a wide range of topics from visualization of spatial information in future scenarios to effective communication of scenario insights to users and the translation of scenario narratives to speculative fiction telling stories about the future. A key finding was that effective scenario communication requires a dedicated effort to develop sophisticated communication and visualization tools with compelling visual design and comprehensible descriptions of scenario contexts, assumptions and results. Another important element is co-production of scenario knowledge between scenario experts and users, e.g. in dedicated workshops. These elements have been framed by some presenters as part of a new field of providing climate change scenario services.

There is a particular need for more and better communication of the SSP-RCP approach and its applications. The SSPs cover far more than the choice of specific model assumptions, they describe different “paradigmatic” socio-economic futures. The relevance and impact of those fundamentally different futures on climate change scenario outcomes still need to be communicated to a greater extent and higher degree of detail. Scenario communication should be considered as a key component of further developing the framework in order to fully unlock its deep transforming power for climate change scenario development, analysis and use. More work is also needed on the communication of integrated climate change mitigation, impact and sustainable development scenarios, which can be derived from an application of the SSP-RCP framework.

The presentations and discussion nicely showed the current status of communication approaches for different types of scenarios. The community is drawing on a wide range of communication levels. On the one end, the SSP narratives found their way into highly imaginative science fiction novels. On the other end classic quantitative scenarios (e.g. mitigation scenarios derived from integrated assessment models) were presented with as clear as possible, fact-focused visualizations. There was consensus that the aim and audience of any communication tool should be clarified in advance and means chosen accordingly. Still, the audience highlighted a further level of communication that offers great promise but so far has been underexplored: Leveraging the imaginative power of scenarios to induce deep learning about the future, e.g. by augmented reality or art in general.

The importance of participatory methods was highlighted. Such methods allow vetting of scenario information and create ownership by scenario users. The audience stressed the fact that nonetheless interactive visualization can also have traps, e.g. when information is strongly condensed. This increases the risk of misunderstandings and missing out on important bits of information.

If communication, visualization and participatory tools are continuously advanced, this will be for the good of all potential audiences, namely climate change researchers, scenario practitioners, and climate change decision makers. Hereby, practitioners could act as knowledge brokers between researchers and decision makers by actively engaging all groups in scenario co-production. In this vein, the development of climate change scenario services can be expected to become an increasingly integral part of many projects and assessments that seek to inform climate change decision makers and thus provide a key contribution to climate change knowledge hubs.

## Demographics

Session title: Deconstructing demographic futures: Population dynamics in the Shared-Socioeconomic Pathways

Session organizer(s): Deborah Balk (CUNY), Cristina Bradatan (Texas Tech University), Susana Adamo (CIESIN), Landy Sanchez (El Colegio de Mexico)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

Deconstruction is a helpful device – but more unpacking is necessary. See extended comments below, including engaging with other modelling groups (UN, GDB).

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

Helps to reframe the narrative. What would be the implications of an older population? A more mobile population? Larger middle-classes? See more on this below.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

1. Deconstructing the SSPs – making how they were built transparent? It's one thing to understand the narrative, but better to understand how they were constructed mechanistic. The existing paper are helpful, but a fuller understanding what's the black box would be very helpful.
    a. E.g., low fertility futures – are these the same everywhere? If not, what are the fertility levels that are used in each country?
2. Improved inputs into the scenario modeling. Examples of this include:
    a. Finer grained inputs such as refined understanding of urban locations, migration patterns, and land-use (place-specific aspects of demography).
    b. Further refinements to population age structure, and connecting changes in the population structure to labor market (including wages, changes in industry and occupation). Can such connections be made in the SSPs?
    c. GDP is important to the SSPs, but well-being and a fuller understanding of population sub-groups would be useful.
        i. In this case, maybe expansion of the narratives is an important first step, particularly to tease apart the effects of a fuller distribution of the income distribution. For example, the middle-class which is growing in most countries, and a class of "strugglers" (those at the lower end of the income distribution, but not formally below a set poverty line), are not well represented in the current scenarios.
    d. Similarly, more nuance and a better understanding of the characteristics of urbanization are important to the scenario modelling. Two cities can look alike in a simple quantitative profile (population size and density) but well-being may be much different in those locations. Not only should the narratives think about these different profiles, but how to quantify them. (See perhaps Solecki et al., 2015 in Urban Climate).

    e. Must take heterogeneity into account, therefore improvements in model input would go a long way towards this.
3. Interest in further downscaling the SSPs (but unclear how far those downscaling effort can or should – this is perhaps a topic for future session as it not well understood).
    a. Evaluating SSPs at a more local scale – how plausible are they in a wider range of places, and how scale dependent are they?
        i. Models need to make it explicit at what scale they work?
    b. What are the thresholds below which we can't go? Is city-level plausible? Sub-city for mega-cities?
    c. Individual and spatial ones matter, for sure. Which others?
4. Helpful for demographers (and related social sciences) to distinguish between population forecasts (which are quantified, even if probabilistic) from the SSPs which are heuristic devices but allow for a range of future possibilities even some of which are not plausible but are still helpful for framing our thinking (e.g. SSP 1.5).
    a. Towards this end, more engagement with demographers (formal demography types?) might be useful. At the global scale, a few groups are working in this domain. What about reaching out to the UN Population Division? Or engagement with the standards setting group of the UN Stats Division? Global Research efforts (like global burden of disease project), and national level research institutes?
5. Ways to build in extreme events into the steady state projections and the path dependency that they create.
6. It is time for model inter-comparison on the social sciences? In particular, in application to data poor regions.

*What are other key highlights from your session?*

Are the scenarios representing the right assumptions – for example, with respect to migration? The answer in our session was definitely NO! They are not sufficiently complex, and the data needed to supporting modelling are also not really adequate, but nevertheless this should not prevent future scenarios from trying to articulate the role of migration in different climate futures. Only thinking about international migration is a limitation, because much more migration is already within national boundaries, and climate change probably stands to increase that, perhaps substantially.

Feedback is needed in the SSP. This is a really important point, and one that the SSP do not yet accommodate, nor to existing population projections. For example, understanding the impact of higher fertility on climate is increased temperature, which should in turn impact fertility. But this feedback is NOT included. Such feedback can be made similarly for aging, migration, mortality and urbanization. Further, some of the feedback can be complex, meaning positively affecting one area and negatively another (age structure and migration, economic well-being and patterns of [some] diseases). A follow-up focused set of sessions (including with modelers, and complementary folks in the qualitative space, present) would be very VALUABLE.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

The session clearly identified city and regional planners as necessary consumers of the scenario-related outputs, but the organizers strongly feel that engagement with national statistical offices, and related social and health science data infrastructures would benefit from a better understanding of what's required to produced demographically informed and nuanced scenarios or applications of those scenarios to their own work product (such as population projections).

This document, fyi, was completed at the Population Association of America annual meeting, with all 4 original organizations of the session: Cristina Bradatan, Landy Sanchez, Susana Adamo, and Deborah Balk present and contribution. Importantly, there are many climate-related sessions and climate-related demographic papers in other sessions at this meeting. So, that's progress. Maybe a 'getting under the hood of the SSPs: everything demographers need to know, and can do to participate in future SSPs" would be good for a session or even workshop at a future PAA.

## Economic modeling

Session title: Shaping the SSP storylines in economy-wide models

Session organizer(s): Bert Saveyn (Joint Research Centre of the European Commission), Rob Dellink (OECD), Dominique van der Mensbrugghe (Purdue University)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

Increasing use of multi-model studies for scenario analysis. However, models, using same drivers, are producing different summary indicators—are these differences driven by model domain, data inadequacies, or the need to pursue more inter-model feedback? For example, should there be some degree of harmonization of the future energy mix between detailed bottom-up energy models and top-down CGE models? Relatedly, as the CGE models rely extensively on calibrated production and demand functions, to what extent can they generate disruptive structural change.

The socioeconomic drivers of the SSPs are used in many multi-sectoral CGE models, but the lack of availability of SSP-marker projections for sectoral economic activity (beyond agriculture and energy) hampers a widespread use of the SSPs in CGE models.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

Implementing the SSP storylines remains a critical area of research particularly in the CGE context that imposes a number of consistency requirements. This research requires multi-model comparison, and elucidation of 'best practices'. Examples include how to implement consumer preference changes across SSP scenarios, be it for energy carriers or food choices, and how to adjust the energy mix including implementing disruptive transition paths.

As mentioned above, the socioeconomic drivers have been helpful for CGE modelling, but the lack of sectoral activity projections have hampered progress to come to standardized scenarios.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

There was some discussion of model validation, stressing the tradeoff between model 'plausibility', i.e. the ability of the models to 'explain' recent the recent past, and the potential for describing disruptive future structural change. One intermediate approach is perhaps to develop a set of model-based scenario indicators that would help improve the confidence in model outcomes, for example the share of labor in value added, steady-state indicators such as the return to capital or the capital-labor ratio.

*What are other key highlights from your session?*

There was a discussion regarding the validity of market equilibrium to determine the prices of goods and factors. There was a recognition that market equilibrium, though the default closure in most CGE models, could be replaced by disequilibrium mechanisms, i.e. the latter were not the exclusive domain of macro-econometric models.

The discussion also dealt with the plausibility of the SSP and other scenario projections when they exclude environmental feedbacks, e.g. climate damages in the SSPs, and materials shortages in the OECD materials use projections. The outcome of the discussion was that most (all?) attendants agreed that it makes sense to not have such feedbacks in the standardized scenarios as they need to allow other researchers to explore projections of environmental damages. But this needs to be communicated carefully.

Are there other interesting scenarios that fall between the gaps in the SSP framework? For example a regional split where the rich countries go 'green' and developing countries continue to develop in conventional ways.

The IIASA DB is very helpful!

An extension of the SSPs to materials use and materials supply risks would be interesting.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

The scenario analyses provided by global CGE models can be beneficial for a wide range of audiences, and especially researchers and policy makers.
Global (and national) CGE modelers would most benefit from additional research in the topic area of this session—with an emphasis on improving multi-model feedbacks and disruptive technologies and other structural changes.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

The GTAP-sponsored 'baseline' project plans to produce a set of 7 papers relating to different aspects of scenario development.

The Energy Modeling Forum has just started a topic on the implementation of Paris Agreement in CGE models, which will entail model comparison exercises heavily involving global CGE models.

## Electrification

Session title: Renewable-based electrification: how can we improve scenarios for clean energy transition?

Session organizer(s): Daniel Russo (IRENA) & Jeffrey Logan (NREL)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The SSP-RCP framework was not explicitly used in the contents presented in this session. Rather, the work focused on scenario frameworks addressing a key element of narratives and elaboration of developments in the energy system – co-evolution of renewable energy and electrification of non-power sectors. Scenario frameworks have previously addressed this topic in a stylised way, largely through the lens of power sector models.

In this session advances were shown to have been made in scenario frameworks on: higher temporal and spatial resolution modelling, across a richer set of electricity end-use technologies in various sectors to adequately capture renewable-electrification dynamics; integration of high-resolution power sector modelling with higher level energy systems modelling of the heating sector; and exploring the role of new technologies resulting from renewable-based electrification (i.e. electrofuels) in wider economy and emissions development pathways.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

Features that helped/hindered develop the scenario frameworks presented in this session included: availability/lack of detailed electricity end-use technology cost, performance, and hourly demand profile data; certain vs. uncertain narratives from national and local governments around industrial and regulatory development; and uncertainty around the role of carbon storage in long-term scenarios.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

Scenario frameworks addressing/including the topic area of electrification with renewables would do well to: increase resolution of power supply and operation strategies (including distribution and utility models) to meet evolving demand; better incorporate urban-scale dynamics and regulations; analyse the integration/interaction of this topic with the hydrogen economy; analyse this topic in less-studied aviation and shipping sectors; better understand the optimal roles of electrification vs. bioenergy in a wider emissions mitigation landscape. Research gaps exist in each of the areas above.

*What are other key highlights from your session?*

Other key highlights from the session included insights into: the need to focus on peak energy demand growth in electrification with renewables - rather than only averages - as peaks can change significantly in terms of magnitude, timing during the day/year, and geographic location, with major impact on infrastructure planning – adequate resolution is key; the importance of urban-scale dynamics and regulations in driving the real-world pace and character of electrification; a theme in results across geographies that the transport sector could be most quickly electrified; the result that electrofuels may only emerge in the transport sector in the absence of carbon storage under stringent climate targets, as the value of permanently removing carbon from the atmosphere is higher than reusing and re-emitting it; and the fact that developments in solar and wind cost are already enabling some key transitions in the absence of policy.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

The methodological and scenario development work presented in this session would benefit power and energy sector researchers and modellers, as well as those in the IAM community in the design of scenario narratives/inputs. Results of the work in this session would benefit policymakers.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

Follow-up activities include: an IRENA international forum on long-term energy scenarios to be held in April 2019; an IRENA report on electrification with renewables in 2019; further expansion by NREL of their Electrification Futures Study in 2019-20; work by Chalmers University on electrification of shipping and aviation; and work by VTT to integrate the modelling of company investment decision-making in the topic. Insights from this session will be taken into account in these activities, and communication will remain open amongst participants re. collaboration opportunities.

## Extremes

Session name: Scenarios for climate extremes and their socio-economic impacts

Session organizer(s): Katja Frieler (PIK), Jana Sillmann (CICERO), Christian Otto (PIK), Matthias Kalkuhl (Mercator Institute), Reinhard Mechler (IIASA)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

Advances were presented in terms of addressing the gap between spatial and temporal scales in terms of global scenarios and regional to local impacts of weather and climate extremes. By incorporating empirical analysis into a macroeconomic model (i.e. DICE), the impacts of tropical cyclones on the structural determinants of growth (total factor productivity, depreciation, fatalities), instead of growth itself, can be estimated and their effects on the social cost of carbon. It is also possible to bridge the scales between global scale scenarios and local relevance by using a Dynamic Stochastic General Equilibrium (DSGE) model that enables to model disaster shocks, which can have long-run effects on macroeconomic outcomes and play a role in the development story of disaster-prone countries such as small islands. The risk assessment of future changes in extreme events can further be extended across time scales by connecting SSP-RCP scenarios to event attribution studies of past and current climate. The well-established scenario storylines (i.e. SSP-RCP framework) can be complemented by the emerging field of event-based storylines to inform decisions (beyond mitigation action) regarding adaptation and emergency planning. Event-based storylines are physically self-consistent unfolding of past events, or of plausible future events, and are similar to scenario storylines to the extent that both are conditioned on a set of assumptions, and they are built from causal arguments, without probabilities attached to them. This will facilitate the link to disaster forensics, which aims at a step change in understanding the contributions of hazard, exposure and vulnerability to specific '(un)natural' disasters. In doing so, it supports the shaping of risk management roles and responsibilities at local to national scales. Synergistic alignment between the complementary research fields of scenario development, climate change and impact attribution and disaster risk reduction may be particularly useful around a projective risk scenario approach for charting out the risk and options space along near to mid-term timescales.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

The SSP-RCP framework targets long time horizons and global scale whereas the impacts of extremes occur more on regional to local scales. In particular, decision time frames for adaptation and disaster management are focused on the near term (e.g., 5-15 years ahead).

The combination of SSPs and RCPs supports studies that aim to extract information or gain knowledge about the effects from socio-economic development versus effects from climate change in terms of impacts of climate extremes.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

More regional and near-term interpretation or translation of SSPs to facilitate impact (risk) assessment of climate extremes taking into account both the socio-economic development (i.e. shaping exposure and vulnerability) and climate change (i.e. affecting climate hazards).

*What are other key highlights from your session?*

Scenarios for climate extremes need to span across spatial and temporal scales and use different modeling approaches (IAMs, global climate models, high-resolution climate models, impact models) and empirical evidence (disaster forensic, socio-economic data).

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

Adaptation planners, disaster risk management, local to regional/national policy makers, economists, climate and impact modelers, etc.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

Commentary in Nature Energy (Katja Frieler et al.)

Workshop on Event-based Storylines in Oslo (April 2019) (organized by Jana Sillmann)

Knowledge Action Network on Emergent Risks and Extreme Events (www.risk-kan.org)

## Finance

Session title: Use of scenarios for assessing climate-related financial risk and opportunity

Session organizer(s): Seth Montieth (ClimateWorks), Chris Weber (WWF)

Use of SSP-RCP scenarios for the financial sector is a new and growing area of research. While use of scenarios for financial analysis is common, overlapping climate-related scenario frameworks are newer, requiring significant stakeholder engagement between the finance community and the climate-related scientific and research communities. These engagements can be considered a translation effort between fields as they require a common language that is often lacking. Tension remains between explorative versus performative scenario elements that might be useful in making financial decisions. The financial community seeks performative metrics with which they can align metrics of financial risk and opportunity. Thus far, these are grouped into two main areas: Physical and Transitional Risk.

Physical Risk refers to exposure to a changing climate, and Transitional Risk relates to company transformation away from emissions-intensive activities. These are highlighted in the Task Force on Climate-related Financial Disclosures (TCFD) that aims to "develop voluntary, consistent climate-related financial risk disclosures for use by companies in providing information to investors, lenders, insurers, and other stakeholders." In order to accomplish this, they are seeking input from the climate-science scenario community, and this input is slowly developing.

In this research session, participants from PIK, CICERO, Acclimatise, the Joint Global Change Research Institute, the EPRI, and IIASA presented their latest work on how climate scenarios might be used in financial decision making. Because this was a research session, the works presented were all research in progress. Instead of notable advances to the scenario framework, the research discussion offered up a set questions for the community to grapple with as it relates to interaction with the finance community including:

- How might the various user needs be addressed in the diverse financial community? Which models and organizations are best positioned to address these needs? Banks, asset managers, individual investors, governments, pensions funds, and companies all have differing needs and no individual model is fit-for-purpose to all users.
- Financial risk in the near-term might not be identified in scenarios/models set to answer questions related to the long-term. Are their modification to modeling efforts that might aid in near-term analysis?
- Downscaling and mapping to firm or asset level analysis requires additional layers of data that are often proprietary or not readily available to the research community. Without this data there are only narratives on hazards and not specific risks that the financial community might use. Who might fill this data gap and is it appropriate for the scientific, research community to be handling such sensitive data?
- How might tensions be addressed between uncertainty, sensitivity and likelihood? Simplifying narratives allows for easier communication but fails to cover the full range of potential activity.
- How might non-financial concerns also be addressed? Exposure to physical risk might trigger capital flight away from areas where investment is most needed. How might scenario analyses incorporate the multiple benefits of investment in these vulnerable regions?

- Some use cases in the financial sector require choosing a single scenario, while others may be better solved using scenario ensembles. How can the research community support financial decision-makers in choosing the right single scenarios or ensemble approaches?

While use of climate-related scenario frameworks in the context of assessing financial risk and opportunity is still newer, it is a key indicator validating how mainstream this community and the use of the RCP-SSP framework has become. Financial institutes and practitioners are now regularly engaging with the climate-related scientific and research community. As interactions grow we expect best practices and guidance to emerge in addition to new research.

## Geoengineering

Session title: Being cognizant of the framing of solar geoengineering in scenario design

Session organizer(s): Masa Sugiyama (University of Tokyo), Peter Irvine (Harvard University), Ben Kravitz (PNNL)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The first presentation (Parson and Reynolds) reviewed the previous literature on solar geoengineering scenarios. They showed that steady progress has been made on the physical science side, as exemplified by the last presentation on the Earth system model (Tilmes et al.), but that much work remains to be done in terms of the “mitigation” scenarios and exploratory scenarios. On the economics side, Belaia incorporated both solar geoengineering and negative emissions in the DICE integrated assessment model, and demonstrated robustness of key features of solar geoengineering (i.e., early and limited deployment) and negative emissions (later deployment, which facilitates phase-out of solar geoengineering). Marangoni and Tavoni employed multi-objective analysis for solar geoengineering since solar geoengineering is not amenable to cost minimization, and demonstrated that despite thorough uncertainty analysis, hard trade-off is a robust finding. Tilmes et al. presented a scenario where temperature overshoot is shaved off with limited deployment of solar geoengineering, and that application of control theory could successfully bring about cancellation of many effects of anthropogenic climate change.

Though the GeoMIP is consistent with the SSP-RCP framework, few papers in the geoengineering scenarios literature have used the SSP-RCP framework as Parson and Reynolds discussed. Belaia showed preliminary results by incorporating population and GDP in the DICE model, but these exercises remain an exception. In fact, the SSP is almost silent about solar geoengineering (digitalization is another notable eaxmple), motivating a next step of research.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

The presenters and the organizers agreed that geoengineering scenarios are often misrepresented and misunderstood. The GeoMIP scenario design assumes large-scale deployment of solar geoengineering to enhance signal-to-noise ratios, but these simulations, which are inevitably accompanied by significant side effects, often misunderstood. For instance, the public might see the framing of the GeoMIP scenario as indicating the inevitability of a termination shock (fast temperature increase following a sudden cessation of solar geoengineering deployment). In fact, the termination shock depends on the scenario assumption of solar geoengineering deployment, which constitutes a policy choice.

Another important point is that solar geoengineering is not in the mainstream scenarios such as the ScenarioMIP / SSP (mitigation and non-mitigation) scenarios presented in the IPCC report. Some fear that mainstreaming solar geoengineering could legitimize its status in the policy discourse, perhaps disincentivizing much-needed mitigation actions. Others, as most of the session participants concurred, argue that treating solar geoengineering would raise alarm, prompting a healthy dialogue on the role of solar geoengineering in addressing climate change.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

As Parson and Reynolds suggested, it would be useful to design geoengineering scenarios that are in line with the SSP framework. Tilmes et al.'s work on shaving off the overshoot with SSP5-3.4-OS represents a good start.

The literature saw many extensions of the SSP framework (e.g., regionalization). Solar geoengineering unfortunately does not align well with the existing SSP uncertainty axes (mitigation and adaptation challenges). It might be useful to create an extension of solar geoengineering scenarios (both narratives and quantification), starting with SSP5-3.4-OS, etc. (Timles et al.'s work was limited to Earth system model analysis.)

Some felt that there has been a lack of coordination between IAM modelers and ESM researchers. The community of researchers working on geoengineering is small but has been growing, and the function of the SSP framework to facilitate integration among disciplines would be crucial for solar geoengineering analysis as the field continues to grow.

Lastly, such scenarios should be carefully reviewed in the upcoming IPCC sixth assessment report or later reports to assist global discourse on solar geoengineering.

*What are other key highlights from your session?*

See the "notable advances" above.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

All kinds of the audiences would benefit since the scenario literature on solar geoengineering is so nascent. In particular, including solar geoengineering scenarios in the IPCC reports would facilitate global dialogues on solar geoengineering, whether this technology would ever be deployed or not.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

The organizers will take up the issue in related upcoming meetings, including the GeoMIP meeting planned in Beijing this summer.

## Governance

Session title: Socio-economic futures and governance scenarios

Organisers: Julia Leininger (German Development Institute), Detlef van Vuuren (PBL Netherlands Environmental Assessment Agency, Utrecht University)

Speakers: Julia Leininger, Constantin Ruhe, Elisabeth Gilmore, Marina Andrijevic, Jonathan D. Moyer
Panelist: Ian Hughes, André Francisco Pilon, Sheila Kong Mukwele

1. Introduction

The session started with a brief introduction by the organizers indicating the importance of better including issues regarding governance and conflict in scenarios. They emphasized that there is a research community in social sciences, which builds conflict and governance scenarios based on the SSPs. At the moment, models cover technical and economic aspects of sustainability challenge s – but do not (or hardly) cover governance and conflict issues. Still, it is clear that (the lack of) good governance, disruptive political changes and violent conflicts are at least as important for sustainable development. One important reason why governance is often not included is the difficulty of translating political change and conflict in mathematical equations. Although there are several reliable sets of quantifiable governance and conflict indicators, governance and conflict is now only dealt with in the storyline part of scenarios, such as the SSPs (SSP1 emphasizes good governance; SSP3 emphasizes conflict).

2. Presentations

The first speakers, Julia Leininger and Constantin Ruhe, further elaborated the theme of the session. Based on the assumption that ignoring political and conflict matters leads to biased scenarios, they indicated the type of indicators that have been developed to deal with political change, governance issues and violent conflict. They furthermore introduced common theoretical assumptions about the relationship between governance/conflict indicators and

established indicators such as GDP. They concluded that it is possible and desirable to quantitatively include governance and conflict in scenarios. The second speaker, Elisabeth Gilmore, presented work on armed conflict and its relationship with GDP growth. Based on the assumption that GDP projections in SSPs are too optimistic and ignore political factors, she presented conflict-corrected SSPs. She estimates a 15-40% decrease in economic growth by the end of the century, depending on the SSP. The third presentation by Marina Andrijevic continued on this theme by showing that similar correlations between income and other governance indicators can be used to describe political developments under the different SSP scenarios. Jonathan Moyer, next, showed how a rich set of indicators related to governance and the SDGs could be modelled using the IFs model – in relation to the SSP. Subsequently, the discussion was started by three brief statements. Ian Hughes showed how explicitly representing actors in models allows to address governance issues in an energy system model. Andre Pilón and Sheila Kong Mukwela, finally, discussed how governance issues are clearly different for different issues and geographic locations.

3. Specific questions

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

Based on earlier work on narrative-based scenarios (e.g. SRES and the Millennium Assessment scenarios), the SSPs pay attention to governance issues as part of the storylines. This, for instance, leads to different assumptions on education and cooperation in SSP1 vs SSP3. Interestingly, in the session several presenters showed that there is already a set of reliable indicators on political factors, governance and violent conflict (e.g. V-Dem, World Bank Governance Indicators, UCDP/PRIO), which quantify political developments over time. This would not only allow to analyse political and conflict effects on established factors in scenarios such as GDP, but also to analyse more explicitly governance goals such as those formulated in SDG16 and SDG17. In several elaborations, income played a key role. However, one might question whether the observed correlation between income and governance as well as conflict indicators suggests that income can be used as a driver – or whether the correlation should be used the other way around: economic growth can only occur in situations with a sufficient level of good governance and peace. Ideally, new models would have governance, conflict and economic indicators co-evolve (just like is done for income in one of the models to develop the SSPs). The presentations also showed other interesting work in relation to the development of governance in scenarios, including actor-based modelling and system-dynamics modelling.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

In principle, the storyline aspects of the SSP-RCP framework are helpful to include governance and governance issues. However, considerable work still needs to be done, in particular bringing existing scenario-building on governance and conflict together and integrating these

comparisons in further scenario-building for sustainable development. Especially new indicators need to be developed that relate governance issues, scenarios and the SDGs.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

See above. In a nutshell: Modell comparison; integrating quantified governance and conflict indicators in SSPs.

*What are other key highlights from your session?*

See above. In a nutshell: There is a lot in governance and conflict research to build on.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

At this point of time, it is important to bring different communities from natural and social sciences together. Social scientists are often not aware that their theoretical and empirical work can inform and enrich scenario-building. In addition, policy makers who are currently struggling with vested interests that hinder effective implementation of sustainability policies (SDG implementation) are interested in learning more about political factors and their interaction with other factors covered in the SSPs.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

There were no specific activities discussed.

## Impact Costs

Session title: Cost of climate change impact and the use of scenarios

Session organizer(s): Shinichiro Fujimori (NIES and Kyoto University), Juan-Carlos Ciscar (JRC)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

Most of the studies presented in this session utilize similar approach in which two kinds of information is incorporated in an integrated modeling platform; namely climate change biophysical impacts and socioeconomic assumptions. The climate change information is mostly represented by RCP climate model information. GDP and population information can be represented by SSP for the socioeconomic side while other socioeconomic aspects are not

always reflected. Parazzo present agricultural sector's representation in SSPs variety. Takakura shows that full SSP RCP matrix is filled by multi-sectoral CGE assessment.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

There are two obstacles related to this research field that should be overcome. First, the extreme events are always burning question but for now they are rarely assessed. It would be due to the limitation of the climate information but there should be some methodological advancement regarding that area. The other missing element is adaptation capacity representation which is one of the crucial SSP characteristics that are originally aimed to be represented somehow. Overall, exposure is well recognized how to assess within SSP-RCP framework.

There is also an issue regarding the GDP and population projections in the EU, as there is an official baseline projection of the European Commission, the Ageing Report, with projections to 2060. The solution was to have an additional run, on top of the SSPs, but maybe having som many socioeconomic scnearios confuses somehow the audience,

Many impact studies have only used RCP8.5, which does not seem to be a good baseline

WGs 1 and 2 could have more harmonized scenarios, in particular, the use of SSPs by the WG1.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

The communication of the SSPs- RCPs is difficult to policy makers. Maybe for the new generation of scenarios, a communication team could advice on e.g. understandable, easy names.

*What are other key highlights from your session?*

VSL discussion is sensitive but cannot be ignored to discuss about the economics of climate change impacts and during the session, it was discussed intensively.
The other topic but related to VSL is how to communicate the GDP and welfare changes with public and policy makers. In general, economists well recognize what they are but usually it is not easy to deliver the interpretation of them to policy makers.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

Climate related policy makers definitely benefit from the information related to the climate change economics. The business people would also be interested in.

Last but not least, the society is an audience missing.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

As we have not yet had any concrete plan, we might want to have a meeting. A review paper or report summarizing the existing literature could potentially be thought as the following up outcomes to identify the prioritized research area. In the long-term, model comparison would be beneficial to improve approaches and could have more robust conclusion.

## Impacts - I

Session name: Use of the SSP-RCP Scenario Framework in Climate Impact Analysis (Part I)

Organizers: Brian O'Neill (University of Denver), Timothy R. Carter (Finnish Environment Institute, SYKE), Kristie L. Ebi (University of Washington)

This was the first of two sessions exploring the use of the RCP-SSP scenario framework in assessing impacts of climate change across a range of sectors and scales. The four presentations in the session first, examined country-level nutrition security (an adequacy ratio) out to 2050 within a global modelling framework, using three SSPs (1, 2, 3) to span the range of GDP and population projections in combination with RCP8.5 climate (Nelson), second, reported a global study using a range of indicators of climate risk across different sectors to compare estimates across three SSPs (1, 2 and 3) in combination with regional climates associated with 1.5, 2.0 and 3.0 °C of global warming for identifying hotspots where targeted risk redulction efforts might be directed (e.g. to address multi-sector risks or risks exceeding key thresholds (Riahi), third, presented results of a study for Africa that applied all plausible RCP-SSP combinations to examine human exposure to deadly heat (apparent temperature of 40.6 °C) and avoided exposure through mitigation (across RCPs) and through socioeconomic development (across SSPs) using two different methods for distributing regional population (Rohat), and fourth, described a bottom-up, co-design approach to coastal adaptation assessment at local-scale in New Zealand, in which three aspects of some key climate-related risks were identified – thresholds (impacts the community didn’t want to see happen), triggers (impacts needed to prompt a decision to act) and signals (changes indicating that triggers or thresholds are being approached) – and these were tested against RCP-SSP scenarios combined with local variants of Shared Policy Assumptions (SPAs), nreflecting local climate policies for mitigation and adaptation (Lawrence, standing in for Cradock-Henry). Note that a fifth presentation originally scheduled for this session was cancelled (Lotze-Campen).
The following points elaborate on the presentations and discussion, addressing specific questions requested for sessions at the Forum.

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

- The nutrition study used SSPs (1-3) and RCPs to explore sensitivities to a range of uncertainties in projections, even though some combinations might be regarded as implausible (e.g. SSPs 1 and 2 with RCP8.5). The hotspot analysis also used the same three SSPs, but in this case in combination with fixed global mean temperature changes, to relate directly to impacts avoided by limiting temperature change to the Paris policy targets.
- The New Zealand study addressed requirements at local level to depart from global SSP narratives (e.g. to reflect treaties with indigenous communities). It was also one of the few studies at the Forum to address climate policy explicitly at local level, developing SPAs to test local adaptation policies for indicators judged salient, credible and legitimate by stakeholders.
- The study for Africa on deadly heat, applied all RCP-SSP combinations judged plausible in the original framework (15 out of 20), but also recognised the importance of uncertainties in some of the key drivers ( in this case two alternative schemes for representing spatial population distribution, which determined exposure).

*What features  of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

- In the NZ study, it was found to be particularly important to limit scenario combinations to a manageable number, hence bounding the complexity of the scenario space whilst at the same time incorporating locally-relevant socio-economic drivers of change into the narratives.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

- The method of constructing SPAs described in presentation 4 could be developed further to address an under-researched aspect of applying SPAs for exploring adaptation options at local scale.
- The heat stress modelling in presentation 3 omitted consideration of pollution or urban heat island effects in combination with high temperature. Both of these aspects would provide a useful add-on dimension for refining RCPs (in the case of pollution) and SSPs (for the UHI). Additionally, there are other potential methods of specifiying demographic projections, especially regarding urbanisation.

*What are other key highlights from your session?*
*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

- Local policy makers in the New Zealand case study regions are already very interested in the scenario methodology, and the future inclusion of technical experts may provide the additional credibility required to analyse alternative pathways and move adaptation planning towards implementation within a regulatory framework.

## Impacts - II

Session title: Use of the SSP-RCP Scenario Framework in Climate Impact Analysis (Part II: Water and Land)

Organizers: Brian O'Neill (University of Denver), Timothy R. Carter (Finnish Environment Institute, SYKE), Kristie L. Ebi (University of Washington)

This was the second of two sessions exploring the use of the RCP-SSP scenario framework in assessing impacts of climate change across a range of sectors and scales. Here the focus of all four presentations was on land use and water. Three presentations reported global analyses using the GCAM Integrated Assessment Model. The fourth focused on sub-grid-scale processes and trade-offs of land use change in Brazil. The first GCAM presentation focused on groundwater depletion, using GCAM to explore sensitivities to all 15 plausible RCP-SSP combinations, five alternative GCM-based climates, three alternative assumptions concerning groundwater availability, two surface water scenarios (reservoirs) and two extreme parameter values for testing sensitivity (15 x 5 x 3 x 2 x 2 = 900 combinations), concluding that results were highly sensitive to the groundwater assumptions (Hejazi). Water scarcity was the focus of the second GCAM presentation, using a full RCP-SSP factorial analysis, with and without RCP-based climate changes (5 GCMs), to investigate the impact of SSP assumptions about water demand and technology on water availability and concluding that in many regions socioeconomic drivers have a larger impact on water scarcity than climate change (Graham). The third GCAM presentation demonstrated the importance of understanding how the management, growth cycle, rooting depth and general physiology of perennial bioenergy crops (Switchgrass and Miscanthus) differs fundamentally from annual energy crops such as maize (corn) and soybean, and this has implications for Gross Primary Productivity (GPP), water use, runoff and ultimately land allocation, with simulations conducted using the new high resolution DEMETER land use model that can provide relevant parameters required as inputs to Earth System Models (Huang). The fourth presentation used a factorial scenario analysis to explore effects of deforestation in modifying local climate such that temperature extremes are accentuated with adverse effects on the agricultural crops replacing the forest, which under some scenarios would produce a conclusion that retaining the forest could be more valuable for agricultural production through climate regulation than removing it (Cohn).
The following points were raised in discussion and are organised according to specific questions requested for sessions at the Forum.

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

- The analysis by Hejazi et al found a robust conclusion of a peak and decline in global groundwater depletion within the next century across a wide range of scenarios facilitate by the SSP-RCP framework; the timing of the peak was most strongly determined by the SSP, and depletion was larger in mitigation scenarios.
- The analysis by Graham et al identified regional patterns of the dominance of societal or climate drivers of deplation rates, across various combinations of SSPs and RCPs.

*What features  of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

- Interpretation of SSPs at regional level can be crucial for determining critical global drivers such as trade, outcomes of which are then manifest in regonal land allocation.
- Different assumptions made in different studies for the same SSP and for the same region can be problematic for undertaking inter-comparison studies, but add richness to the scenarios too. It is especially important to be fully transparent about these assumptions.
- Many examples were presented of a full factorial analysis using the 15 RCP-SSP combinations regarded as plausible, and then refined by exploring known uncertainties in some key variables (e.g. by using multiple climate projectons, impact model assumptions, ranges of parameter values). Nevertheless, it can still be very difficult to isolate the relative contributions of different drivers in producing certain outcomes. Scenario design is a paramount consideration, therefore, in identifying key processes and influences.
- It is an open question whether there is sufficient regional heterogeneity in SSP assumptions to support conclusions (such as those in Graham et al) about regional patterns of drivers and outcomes.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

- The potential value of model hindcasting was raised, whereby GCAM simulations could be run over past periods for which observations are available to compare with model behaviour. Such experiments have been undertaken in a limited sense, but it was agreed that more comprehensive hindcasting runs might yield  useful insights
- Population was a key driver for several of the indicators presented, but its relative contribution to some outcomes was not always clear compared to that of other drivers (e.g. in the case of water scarcity). One suggesions would be to refine the scenario design such that the effect of individual drivers like population can be isolated and studied separately
- The role of adaptive management ameliorating some of the impacts of climate change simulated in IAMs may be under-estimated and requires more attention. For instance, soy farmers confronting higher growing season temperatures due to forest loss are very likely to adapt their crop management strategies, by altering planting dates, substituting crop cultivars or even shifting to alternative types of cultivation.

- One suggestion noted was the idea that different regions might exist within different SSPs, with potentially interesting implications for the interactions between regions, though this idea would seem to contradict the fundamental global nature of SSPs.
- There are many unexplored opportunities still available for developing Shared Policy Assumptions, especially at regional and local scales, where outcomes can be extremely sensitive to SPAs
- Do we need SSPs or SSP variants with more regional heterogeneity in development pathways?
- ESM simulations for RCPs would benefit from including explicit energy crops due to their differential response to climate in terms of carbon loss, runoff, and other factors

*What are other key highlights from your session?*

- see summary at top of page.

## Impressions

Scenario title: Downscaling and enriching the RCP-SSP scenario framework as a basis for co-creating integrated and transformative solutions to high-end climate change

Organizers: Paula Harrison (Centre for Ecology & Hydrology, UK), Timothy Carter (Finnish Environment Institute, SYKE)

This session presented methods, results and some key messages emerging out of the 5-year European Commission funded IMPRESSIONS project that applied the SSP-RCP scenario framework, in conjunction with a normative visioning exercise, to investigate potential impacts of high-end scenarios in Europe and to explore alternative policy measures and pathways for approaching visions for a sustainable future. The four presentations in the session first, introduced the IMPRESSIONS project objectives and overall approach (Harrison), second, explained how scenarios were co-developed with stakeholders (Pedde), third, illustrated how the scenarios were applied in a range of models simulating impacts and adaptation responses for number of key indicators, and how the model outcomes were then compared against values for the indicators that corresponded with visions of a desired future in 2100 (Rounsevell), and fourth, outlined how stakeholders and researchers worked together to define the indicators, analyse the model results and co-construct pathways designed to achieve the visions in case studies at the transboundary watershed and municipality scale (Pinter).
The following points elaborate on the presentations and discussion, addressing specific questions requested for sessions at the Forum.

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

- Four SSPs (1, 3, 4 and 5) were downscaled and enriched using a participatory process in five case studies at different scales: continental scale for Europe, regional scale for

Central Asia, national scale for Scotland, transboundary river catchment scale for the Tagus river basin in Iberia, and local scale in Hungary for two municipalities.

- The SSPs were matched with two RCPs (4.5 and 8.5) to create four integrated climate and socio-economic change scenarios.
- These integrated SSP-RCP scenarios were applied to a wide range of impact models to assess risks and opportunities for each case study, including cross-sectoral trade-offs which emerge under different SSP-RCP combinations.
- Stakeholders developed adaptation and mitigation pathways in the context of each SSP-RCP scenario, which consisted of sets of time-dependent actions and strategies, to move closer to visions of a desirable future which were developed through a participatory process for each case study.
- The efficacy of the adaptation and mitigation pathways in achieving the vision under the different SSP-RCP scenario contexts was assessed using modelling and qualitative analysis. This was used to highlight where stakeholders could strengthen the pathways.
- This resulted in a set of pathways that work in all SSP-RCP scenarios, with different emphases for each case study, to achieve the vision of a sustainable future. In each case study, combinations of transformative solutions identified in collaboration with stakeholders accelerate progress towards the vision. The types of transformative solution vary by the SSP-RCP scenario context.
- In applying the IMPRESSIONS methodology, the SSP-RCP framework provided a consistent global framework for developing multi-scale scenarios and building blocks that could be flexibly utilised by the project team. The parallel process of scenario development meant that it was easier to associate the socio-economic storylines with different levels of climate change. Furthermore, the conceptual link between adaptation and mitigation helped with ensuring equal treatment of both issues within the project (although note that we converted them into alternative axes based on drivers within the project – Inequality vs Carbon intensity).

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

- Although having challenges to adaptation and mitigation on the axes was broadly useful for IMPRESSIONS, for other IAV studies it can be constraining if they are only focusing on impacts and adaptation. Also the climate-centric nature of the axes can be constraining for involving a wider range of environmental change studies/problems.
- The SSP-RCP scenario framework and IMPRESSIONS methodology is top-down. We emphasised bottom-up insights within case studies through the participatory scenario enrichment for local/regional context and through a visioning exercise. However, it would be nice to have a process to incorporate this bottom-up learning into the global scenario framework (this forum may be a first step to doing this).
- There are no guidelines for applying the SSP-RCP framework in sub-global assessments. IMPRESSIONS used a single consistent methodology across all case studies, but many other methods are available (as presented in other sessions at the conference). It would be great to have a website, portal or database where sub-global

assessments can upload their method/process, narratives and quantifications to enable learning and capacity building in the community.

- Terminology of “Pathways” in “SSPs” was confusing for stakeholders as it is different from the pathways development and analysis that was conducted in the project. Here, pathways are defined as time-dependent sequences of actions and strategies undertaken by a specific actor or group of actors. Hence, we reframed the SSPs as scenarios in all communications with stakeholders. We also had some issues with the naming of SSP5 as fossil fueled development when it related to positive impacts.
- One of the key assumptions of global SSP5 is that high human and social capital are coupled with conventional-fossil fuel energy development and high skyrocketing GDP growth. This was challenged in some local SSPs and especially in the development of the adaptation and mitigation pathways. We found that a tipping point was reached at different time horizons within each case study when the stakeholders felt that the logic no longer held as environmental degradation would be so severe it could not be ignored. This tipping point was reached sooner in case studies which are already environmentally stressed (e.g. Iberia) than in those with few environmental stresses (e.g. Scotland). These findings could be used to reflect again on the global SSP5 assumptions.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

- The European SSPs were developed by in part mapping existing participatory socio-economic scenarios for Europe onto the global SSPs. For SSP1 the match was imperfect because the existing European scenario assumed negative GDP growth. An SSP1 variant that considers degrowth may be useful. SSP5 could not be matched to the existing European scenarios and was created from downscaling the global version.
- In IMPRESSIONS the saliency and relevance of the SSPs was tested with stakeholders. This learning (from other participatory studies as well) should be consolidated for developing future modifications to the global SSPs. In particular, it has been noted that the current global SSPs are highly based on a Western science worldview and values (and perhaps even more specifically on views from IAMers). It is key to open up and test the framework in different non-Western and local contexts either using the existing SSPs as a starting point or developing entirely new SSPs.
- SPAs were not explicitly explored in IMPRESSIONS, although we assumed mitigation policy was essential for those scenarios linked with RCP4.5 and we developed adaptation and mitigation pathways under all SSP-RCP context scenarios, which could be considered similar to local SPAs. Overall, however, there seems to be a gap in local/regional applications of the SPAs within the SSP-RCP framework, in particular for adaptation policy.

*What are other key highlights from your session?*

- Some perverse or unexpected consequences emerged from modelling impacts under the SSP-RCP scenarios. The most notable was under SSP1-RCP4.5, which resulted in a large scale expansion of agriculture across Europe at the expense of forestry. This is driven by the need to meet increased food demand due to the increasing population and reducing imports, existing agricultural land being more extensively managed than currently for environmental purposes, and a shift from meat to dairy products.
- Socio-economic factors in the SSPs much more strongly drive changes in land use and food production than changes in climate, sometimes overriding any differences in impacts due to low-end (RCP2.6) and high-end (RCP8.5) climate change. In past research much more focus has been put on climate uncertainty, whilst there is a massive gap/void on understanding and quantifying uncertainties in socio-economically determined processes.
- Using the SSP-RCPs as the context for developing adaptation and mitigation pathways revealed some surprising outcomes. In particular, SSP3-RCP8.5 was found to be a source of opportunity on medium and longer time scales for radical transformation that is not represented in the global scenarios.
- In IMPRESSIONS we were only able to interact with stakeholders during three workshops in each case study during the project's five years, which was supplemented by online engagement in between the workshops and a few smaller face-to-face workshops in the Hungarian case study. There was a discussion in the session on how intensive the stakeholder engagement process needs to be in order to have an impact on decision-making. There are obviously resource implications which can limit this, but in the project we were able to interact with stakeholders more intensively in the local case study at the municipality scale, which enabled greater impacts in local decision-making.
- The difficulty of extracting stakeholders from worldviews conditioned by present-day policy contexts was raised. Perhaps there would be value in spending time with stakeholders in understanding where they have difficulties with global narratives, and unravelling some of the preconceptions and cultural biases that might underpin their viewpoints.
- Stress-testing of current policies within the SSP-RCP framework can be useful for encouraging stakeholders to think beyond current policies.
- The exploration of climate extremes in impact modelling was discussed. This was not a focus of IMPRESSIONS as most impact models used daily or monthly climatic means. The project focus was to explore impacts due to multiple drivers (climate combined with other socio-economic drivers), including cross-sectoral or cross-scale interactions between impacts.
- Visioning was applied in IMPRESSIONS, but questions were raised as to whether the visions that were co-created in the different case studies were subsequently adapted during the stakeholder engagement process. Visions are often based on today's values, and so might be challenged as their implications are followed through in more detail. Furthermore, there may be different perspectives on desirable futures, so it might be more representative of different worldviews to present several alternative visions rather than just one. In the project, the visions could be adaptated as stakeholders developed

their pathways (partly to overcome the problem that visions tend to be intuitively static and based on today's values).

- Stakeholder feedback on the value of the project outcomes was also discussed and whether this was simply an awareness raising exercise or rather if the outcomes were found to be of value for decision-making? A stakeholder survey conducted towards the end of the project showed that over half of the respondents stated that they had changed their own decision-making process to some extent as a result of information provided. Several stakeholders saw the project as a strategic investment of their time, using project outcomes to help legitimise particular policies and strategies they intended to pursue or were already following. This result is both highly encouraging for co-creation processes of this kind, but also emphasises the usefulness of undertaking detailed monitoring of stakeholder opinion and feedback throughout the process.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

- It was discussed in the session that it is important to make outputs from the scenarios available to decision-makers in friendly formats. IMPRESSIONS put a lot of effort into this through creating the "High-end Solutions" Information Hub. This contains videos, inforgraphics and summary outputs aimed at decision-makers (practitioners and policy-makers) and researchers. We also included step-by-step guidance on each part of the project methodology (see http://www.highendsolutions.eu/) aimed at researchers who may wish to repeat the methodology in their own case study. In order to be truly useful in the local context, the information has to be available in the relevant local languages. Many projects (including ours) underestimate the amount of time and effort needed to do this.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

- The IMPRESSIONS project finished at the end of 2018, but consortium members are continuing to work with the SSP-RCP framework in many other projects, some of which have emerged from IMPRESSIONS. We will also continue to publish all the methods and outcomes from the project over the coming year (we have a special issue in Regional Environmental Change coming out in 2019).
- The project will also be presented at the European Climate Change Adaptation conference being held in Lisbon in May 2019.
- We are also on the lookout for any other funding opportunities that will allow us to take forward this work!

## Inequality

Session title: Inequality and poverty, projections and distributional consequences for climate

Organizers: Narasimha Rao (IIASA), Julie Rozenberg (World Bank), Franziska Piontek (PIK)

We had a rich set of case studies that illustrated the range of issues to which the themes of heterogeneity and inequality can be brought to bear: assessing damages from climate change (e.g. heat stress) as well as mitigation impacts (NDCs in Brazil); assessing impacts on households or production sectors within countries (e.g. trade effects on agriculture in the US Midwest), or differential impacts of temperature on economic activity; different scales of impact, from the grid-level, to sub-national to the global; different objects of analysis of distribution, of population, of income and consumption and temperature exposure. We also had a diverse set of tools that were used, including national CGEs and a global econometric model. We did not have specific presentations from global IAMs.

The discussion brought up a number of gaps in the literature on representing dimensions of social heterogeneity that impact the assessment of damages, the response to climate change (e.g. migration), and the impacts of mitigation policies. These include:
- Age distribution, and differential impacts over the course of a life
- Levels of education, and the capacity to adapt

A key point of discussion was the drivers and effects of migration:

- future projections of impacts do not take into account that people simply would move away or not move to certain locations in the first place if it is too hot (e.g. different urbanization patterns)
- migration is not driven solely by temperature, but by wage differences and other factors.

Historically, climate has not played a big role in migration decisions. However, the future may entail unprecedented temperatures, but at a broad regional scale, which makes migration more attractive but difficult (you would have to move much further). Urban/rural differences in temperature and income may be important to model.
- Link to conflicts is important and under-explored.
- Some work on limits of what temperature people can physically survive – what would that mean?

Synthesis
Overall, it seems a key emergent theme is that we need much better representation of vulnerability (this came up in the urbanization and inequality sessions). There are some data that are out there, which need to be better 'marketed' and incorporated into impact assessment. SSPs provide information on age structure and education distribution (and there is work to downscale this) and income inequality; There are also data in household surveys in some countries on age and education.

Another theme is that migration is an important dimension that is understudied, and potentially over-attributed to climate impacts. Scale of analysis matters here.

A common finding is that exposure to climate change seems to be impacted as much, if not more, by future socioeconomic characteristics (population and income distribution), more than

whether people end up in a 2C or 1.5C world. This emphasizes the importance of representing social heterogeneity and inequality in future studies.

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

We had one study that used grid-level population data from the SSPs to assess the population at risk from climate change-driven temperature increases under 1.5C and 2C stabilization scenarios.

Another study assessed economic impacts of climate change at the grid level using statistical analysis of historical data, but did not project these into the future. It is conceivable that this work can be extended in the future, using SSP downscaled income data (that we at IIASA have developed) to project out economic changes from grid-level climate impacts in the future. Neither study interpreted their results in terms of inequality as such. However, it is conceivable that, both studies could in the future examine the implications of their work for inequality, particularly now that downscaled income data (that IIASA now provides) are available.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

As discussed above, grid-level population and GDP projections are useful for examining detailed climate impacts.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

Migration projections at any feasible level of spatial granularity would enhance the work that was presented. As indicated above, downscaling of SSP indicators, such as income, provides data compatible with the granularity of climate impacts to enable local impact analysis. A general challenge in the SSP-RCP framework also pertaining to inequality is the endogeneity problem of impacts and adaptation. If impacts are applied to the SSPs, autonomous adaptation measures are triggered, leading to changes from the baseline. And how do you separate the adaptive capacity embedded in the SSPs from targeted SPA-type adaptation measures in practice in modeling? These questions require a broader discussion.

*What are other key highlights from your session?*

See Page 1 above.

## Infrastructure

Session title: Using a scenario approach to reshape the debate on global infrastructure investment needs

Session organizer(s): Julie Rozenberg, Marianne Fay (World Bank)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The World Bank presented a new work program, summarized in a report called “Beyond the Gap”, that uses a scenario approach (built around the SSP-RCP) to assess future infrastructure investment needs. Up to now, infrastructure investment needs assessments had projected future needs based on past data or had used benchmarking methods. This exercise is the first assessment of its kind and has been met very positively by the policy community. Several of the sectoral studies that were done for the report were presented during the session: (1) a first assessment of global transport infrastructure needs under several SSPs and climate change mitigation targets and (2) the most comprehensive global assessment of investment needs in coastal protection using several SSP/RCP scenarios. In addition, an innovative study looking at the decarbonization of the building stock was presented. Buildings are not usually represented in IAMs and thus in decarbonization pathways, and yet they are long-lived infrastructure that require specific intervention. Finally, a case study that used climate scenario for infrastructure planning was presented. This is also an innovation because this type of planning exercises is usually not carried before deciding on infrastructure investments.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

For the World Bank study, the SSP-RCP framework helped build consistency between all the sectors, by providing common population, urbanization and GDP trajectories as well as common climate change impacts or climate mitigation targets.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

The papers that were part of the World Bank study usually found that what matters for infrastructure investment needs are not the choice of the SSP but rather policy choices and variables related to governance. Therefore, it might be useful to add this dimension to the SSPs if they are to inform research on economic development. A key aspect of infrastructure services is the ability of countries to regularly maintain the infrastructure stock, which is also related to governance and institutions.

*What are other key highlights from your session?*

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

The World Bank work presented during this session was designed to inform policymakers from international institutions or finance ministries, as well as academics working on infrastructure needs assessments (there are few).

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

Another report on infrastructure resilience is under preparation at the World Bank, and uses some of these scenarios. The annual workshop of the DMDU Society will be in Delft in November and often has a strong focus on infrastructure planning.

## IPCC AR6

Session title: Use of scenarios in IPCC's 6th assessment cycle (AR6)

Organizers: Jan Fuglestvedt (CICERO), Ramon Pichs-Madruga (CIEM), Anna Pirani (ICTP)
Session Chair: Jan Fuglestvedt (IPCC WGI Vice Chair, CICERO)
Facilitator: Wilfran Moufouma-Okia (IPCC WGI, TSU)

1. Introduction by Jan Fuglestvedt:

Jan Fuglestvedt gave an introductory remark, with a brief overview of the IPCC Sixth Assessment cycle and ambitions to use scenarios in a more integrated way across Working Groups (WGs). He also reflected on the activities and reports in 6$^{th}$ cycle – with 3 special reports (SR1.5, SRCCL, and SROCC) across WGs, in addition to the main assessment report from the WGs and the final product, the Synthesis Report (SyR). He emphasized the importance of the new modes of working across disciplines and WGs that have been developed during the production of the three Special Reports – and the great potential this represents for further work across WGs and communities. He also pointed to the integrating role that scenarios can play across the Special Reports and WGs and the importance for the coming Synthesis Report.

2. Invited presentations:

Presentation 1: Title: "Role of scenarios in SR1.5: experience from a fully integrated 'case study' for the use of scenarios within the IPCC AR6", Joeri Rogelj (CLA in the SR1.5, LA in Chapter 6, AR6 WGI)

Objective:

Discuss lessons learned from the SR1.5 regarding scenarios as tools for supporting IPCC assessments, considering this IPCC special report as a fully integrated 'case study' for use of scenarios within the AR6 cycle.

Methods/Framework/Key dimensions:

- SR1.5 is the first IPCC report to be produced after the SSP-RCP framework was released and consisted of 5 chapters
- SR1.5 span across the 3 WGs

Degree to which the RCP/SSP literature and framework helped develop the SR1.5

- There was a large set of scenarios available for the assessment – out of which 530 were SSPs-based scenarios;
- Large body of studies was made available on time for SR1.5 through an impressive effort from the research communities worldwide
- The availability of many scenarios was important for assessing the carbon budget
- SSP-RCP framework helped to make sense of socioeconomic variations
- SSP-RCP framework helped to make sense of missing scenarios, which could be identified and interpreted thanks to the framework
- SSP-RCP framework helped to identify and quantify the enabling socioeconomic conditions
- Explain scenario diversity with clear narratives
- Linkage with SDG and other assessments

Key areas for improvement (lessons learnt):

- Scenario design biases (disconnect between end-of-century SSP/RCP scenario design and climate policy; Implicit implication of not caring about climate change or mitigation efforts until we reach 2100)
- Scenario variation are welcome (variations beyond SSP/RCP)
- Policymakers do care about near-term and peak warming
- Need for better integration between WGI and WGIII (climate response to emission remain uncertain; communication between communities can hedge against surprises and unintended scenario)
- Large uncertainty (see Chapter 2 section 2.2)
- Deeper integration representing impacts on the system is desirable
- Scenario data are essential
- IIASA has made available a scenario database
- Openness of data is essential to allow new communities to tap into resource before and during the assessment
- Weakness in the framework design lead to reduced policy-relevant and bias literature towards at times less useful scenarios
- Climate response to emissions remains uncertain
- Variations beyond SSP/RCP framework should be encouraged
- Foster improved  scientific understanding in less established areas

Questions:

- Elmar Kriegler: how important are socio-economic assumptions in the SSP-RCP framework, compared to climate related uncertainties? Can we disentangle these uncertainties? The question was identified as an area of future research.

Key conclusions/challenges

- SSP-RCP framework greatly contributed and facilitated the assessment of 1.5°C-related scenarios in SR15
- Weaknesses in framework design lead to reduced policy-relevance and biased literature towards less useful scenarios, away from peak warming
- Tools to link assessments of physical science and impacts into scenarios will become increasingly important
- A balance should be pursued between framework studies and studies exploring novel directions and variations
- Openness of data is essential to allow new communities to tap into this resource before and during the assessment process

Specific recommendations:

- There is a critical need for better integration between WGI, WGII and WGIII

Presentation 2: "Perspectives on the use of scenarios across WGs in AR6: With WGI as point of departure
By Claudia Tebaldi (LA in AR6 WGI, Chapter 12) with Malte Meinshausen (LA in AR6 WGI, Chapter 1)

Objective:

- Provide a sense of where scenarios are used in the AR6 WGI report

Methods/Framework/Key dimensions:

- Kick off with Chapter 1 which describe scenarios, concepts, history, and puts SSP-RCP scenarios into the context of other scenario types (e.g. SRES). Also describes what scenarios are used across the WGI report;
- There is a focus on 4 scenario from Tier 1 of ScenarioMIP + SSP1-1.9 (relevant to Paris 1.5°C target)
- Chapter 1 also discusses the value of scenarios as organizing and integrating devices within WGI and across WGs, and also within and across scientific communities.
- But, the report will also consider non SSP-RCP scenarios (e.g., idealized scenarios like 1% CO2 increase for process level understanding; warming levels and cumulative carbon emissions as additional aggregating devices; physically plausible low probability high impact 'scenarios' in the context of the risk framework.

- Scenario generation, use and assessment is not a linear process flowing from WGIII communities (where emissions and harmonization are produced) to WGI communities

(where scenarios are run through Earth System Models to produce future projections of climate changes) to WGII communities (as the main customer of those projections used in impact research): WGII and WGIII communities have a role in designing socio-economic future narratives and drivers that are at the origin of emission pathways; WGI communities also plays role in scenario "completion" with aerosols, GHG concentrations, ozone fields, and natural forcings. Through calibration/emulation or "expert judgement extrapolation" WGI also provides the tools for carbon budgets, temperature assessment of scenarios, temperature exceedance assessments etc. which connects to WGIII and mitigation policy considerations.

- Scenario choice for global to regional projection: Tier 1 of ScenarioMIP consist of SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5, and the Paris 1.5C target scenario is taken from Tier 2: SSP1-1.9. There is also an effort to consider the following warming levels: 1.5C, 2C, 3C, 4C (possibly higher – these are just initial choices).

- Chapter 12 connects explicitly WGI and WGII assessments. This chapter aims at providing projections for impact-relevant hazard indices, and will use SSP-RCP scenarios to provide information for regional/sectoral chapters in WGII.

- One section of Chapter 12 will adopt warming levels and connect to Chapter 16 in WGII for the assessment of Reasons for Concern.

- Chapter 11 on extremes will mainly adopt warming levels to organize its projections, but will consider effects of regional forcers (e.g., land use, aerosols) that are scenario specific when they challenge the scaling assumption across global average temperature levels.

- Process Chapters (e.g., 5, 6, 7, 9, i.e., Carbon Cycle – SLCFs - Water Cycle – Ocean, Cryosphere, Sea Level) will discuss high end projections and potential surprises using idealized scenarios or general categories of low/high warming, low/high mitigation rather than focusing on specific SSP-RCP.

- Relevant aspects from the SSP-based scenario composition will trickle down through land-use changes (carbon cycle implications), air pollutants assumptions (SLCFs), and aerosols (Water cycle).

Key conclusions/challenges:

- Selected scenarios, and a large part of the science assessed, for AR6 WGI will be CMIP6 SSP-based scenarios.
- WGII will mainly assess literature based on CMIP5 RCPs.

The disconnect of timeframe between WGI and WGII assessments poses some challenges

As a device to mitigate the effects of this disconnect, and in general as a provision to allow continuity across generations of scenario development and corresponding projections, Tier 1 of ScenarioMIP includes 3 new scenarios that can be directly related to three CMIP5 RCPs:

- SSP1-2.6 <-> RCP2.6
- SSP2-4.5 <-> RCP4.5
- SSP5-8.5 <-> RCP8.5

Only if new model simulations are at odds with the old (for example as a result of a significantly different distribution of Equilibrium Climate Sensitivity among the CMIP6 models compared to their CMIP5 counterparts) the comparison and integration of WGI and WGII assessments will be challenged.

Presentation3: “Perspectives on the use of scenarios across WGs in AR6”: From WGII perspective. By Katja Frieler (LA AR6 WGII Chapter 16)

Objective: Discuss scenarios used in WGII, particularly Chapter 16

Methods/Framework/Key dimensions:

- Presentation is focused on process-based impact models as one part of the WGII assessment;
- Biophysical or socio-economic impacts of climate changes are addressed by a wide range of specific models (e.g. hydrological models, crop models, biomes models, health models etc.) developed by different modelling groups all around the world. Large amount of possible choices regarding climate forcing data (not only regarding scenarios (RCP) but also regarding the applied GCM) and socio-economic storylines will cause a challenge to assess aggregated impacts on e.g. the economy, migration etc. (reason for concern plots)
- Socio-economic changes represent an important driver of impacts changes. They introduce a time-dependence of projected impacts. May require additional dimensions going beyond “global mean temperature change” to summarize results.
- Sector specific and cross-sectoral modelling intercomparison exercises are underway (AgMIP, FishMIP, ISIMIP). ISIMIP protocol will account for WGI selection of “core scenarios” and try to cover at least part of them.

Challenges:

- Translating socioeconomic drivers into impact modelling will often take more time than left for AR6 contributions:
- Large forcing data are requested by process-based impact models (e.g land use and irrigation patterns, fertilizer input, nitogen deposition, fishing intensities, flood protection, dam location and capacities)

Key recommendations/conclusions:

- For WGII it is desirable to have a harmonization of scenarios across WGs
- Process-based impacts models used within the impact modelling community do not only account for climate change but also for socio-economic changes. As such they could also be used to provide a kind of “reality check” for mitigations measures discussed in WGIII regarding e.g. the SDG (What does large scale bio-energy production mean for biodiversity? What does climate change mean in terms of variability in renewable energy supply? etc.). To this end a common “core set” of scenarios would be quite appealing.

Presentation 4: “Perspectives on the use of scenarios across WGs in AR6: From WGIII and SRCCL perspective.” By Kate Calvin (CLA SRCCL, LA AR6 WGIII Chapter 3)

Objective:

- Provides current status of SRCCL and plans for WGIII main assessment report. Since neither report is public, the presentation focuses on what is in the approved outlines, the process, and potential challenges, rather than any content.

Methods/Framework:

- SRCCL = Special Report on Climate Change and Land. But the official title is “Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems”.
- The complexity of the SRCCL title has some implication for scenarios to be used
- Chapter 6 of the SRCCL is the only place where scenarios are included in the approved outline, but the chapter has a lot of other items to address as it deals with interlinkages between desertification, land degradation, food security and GHG fluxes: Synergies, trade-offs and Integrated Response Options (~40 pages). This chapter will combine interactive effects between desertification, land degradation, food security and GHG fluxes, using both bottom-up studies and scenarios
- WGIII outline has scenarios almost in every Chapter, though more pronounced in the following chapters: 1, 3, 8, 9, 10, 11, 15 and Annex C (scenarios and modelling methods)

Why scenarios?

- Scenarios could help link across communities, disciplines, and chapters
- If all research communities used the same scenarios, we could have a more complete understanding of the world under that scenario.

Challenge with using scenarios

- Comparing across model, studies, and regions (e.g. from AR5 where IAM collected 1184 scenarios/studies). There can even be significant uncertainty within one model across studies, as other factors are changing (e.g., GCAM in the AR5 database)
- Choosing scenarios (do we need to subset?) what about the relevance of model signature/structural uncertainty?)
- Collecting information

- How to assess land degradation, desertification, sustainable land management, food security in one single scenario?
- How to pull out regional granularity, how do we collect that information?
- Need a way to collect/provide meta-information that is easily accessible to producers and consumers of the data

Questions:

- Why is it difficult to quantify SSP-RCP connection in the WGII MIP? – This is not impact-model specific challenge
- WGII question/comment: Sensitivity to model is likely to get worse in AR6 and this will make impact model projection difficult. The time availability of CMIP6 add an additional challenge for the impact assessment in AR6.

The questions initiated discussion.

Presentation 5: "Scenario development and use outside the IPCC: AR6 as an opportunity to provide guidance": Vanessa Schweizer (Univ of Waterloo, Canada)

Objective:
How to implement SSPs in communities and firms to perform customized scenario analysis outside the IPCC realm?
How to translate all the options available from the SSP-RCP framework?
Provide guidance on what good scenario thinking is to knowledge users (i.e., consumers of IPCC reports) and why it is needed

Key recommendations:

- Need further guidance on how to use SSP and RCP scenarios (contrast ready-made scenarios (prevailing focus of scientific community) vs. capacity for scenario thinking among knowledge users)
- Echoing ideas presented in other parallel sessions at the Scenario Forum, IPCC could foster the ability of the research community to help knowledge users with their learning-by-doing process
- IPCC making good progress on using scenarios to coordinate research across WGs. Further research/guidance still needed on a bottom-up approach for scientific assessment (a research synthesis design issue)
- Knowledge users (i.e., communities, firms) are encouraged to independently apply SSP and RCP scenarios for their particular decision contexts. What are the consistent conclusions that can be drawn across these independently derived studies?
- Concerns about internal consistency have come up at various sessions at the Scenario Forum. Even with imperfect SSP applications from knowledge users, we can still investigate/learn something from them through focusing on shared scenario elements

Presentation 6: “Scenario-based storylines for synthesis” (Brian O’Neill) CLA AR6 WGII Chapter 16

Objective:
Role and use of scenario for the synthesis report (some ideas on how to do it – through scenario-based storyline)

Methods/Framework:

- What is meant by scenario-based storyline and what benefit this might have as an idea?
- SR1.5 provides a good definition of scenario storyline; the key elements of that definition are similar to the key elements of the definition of physical event-based storylines.
- Storyline examples: SSP3 (regional rivalry) describing how and why the world will unfold into this scenario? See Dessai et al (2018) on narrative for a physical phenomenon, moisture availability over India
- Idea for the SYR: Develop integrated storylines for synthesis, based on the assessment from WGI, WGII, and WGIII
- Example of storyline: Illustrate dependence of risk on future climate, societal conditions, and responses; a partial example is provided by SR1.5 for mitigation scenarios, illustrated by SPM Figure 3b.

Pros and challenges:

- Pros: storyline well suited to integration of disparate type of information; can represent relationship that can't be well modeled; more effective means of communicating risk
- Challenges: perceived lack of rigor; normative aspect of selecting and creating storylines; ability to do "new synthesis" in SYR
- Implication: begin to identify candidate storylines; include relevant assessment in individual WG reports; If storylines for synthesis not possible in IPCC, then it can be pursued in the scientific literature:

Question time/Broad discussions:

- WGI only focuses on the geophysical part of climate change and so, can WGI be realistically involved in storyline?
- Elmar Kriegler: How to manage the integration between WGI, WGII, and WGIII and SSP-RCP is meant to foster the integration across WGs in the AR6. So if we don't have CMIP6 in the impact assessment, then the integration will be challenging;
- Brian O'Neill: The storylines that integrate across WGs can be based partly on SSP-RCP scenario-based literature, but can draw on other types of literature as well.
- Sonia Seneviratne: In SR1.5 we develop a cross-chapter box storyline, based on 3 scenarios (global warming of 1.5°C, 2°C, and 3°C storylines). The main issue for AR6 is the timing and availability of CMIP6
- Carl-Friedrich Schleussner: how the scenario thinking can inform the UNFCCC global stock take? Joeri Rogelj: in the WGI FOD, we are discussing this issue in the framing Chapter
- Are you considering who the audience is for the storyline scenarios? Brian O'Neill – thinking about the government representatives

Key ending statement from presenters:

- Claudia Tebaldi: Need to draw a stop in the CMIP machinery for 3-4 years to catch up - throw a wrench in the cog that is CMIP to stop it for a cycle and allow WG2 work and literature to catch up. Concerned regarding questions about the SSPs themselves perhaps needing revisiting, for the same reason, which is the need to allow the assessment that is building on them to play out. Therefore, hoping that the plan would be to enrich the current SSPs, not to start from scratch.
- Joeri Rogelj: The SSPs contributed significantly to the success of the SR15 integrated scenario analysis, but that SR15 experience also highlighted some important limitations of the current SSP/RCP framework, the most important of which is to focus on 2100 and thus by design neglecting the near-term and peak warming. Policymakers have shown to care more about this than about 2100 only. He also reflected on the use of storylines to bring together the synthesis of the AR6 and commented that it would be important to define from the onset which aspect (or aspects) we want to clarify through the contrasting stories. In the SR15 this was clear: the differing use of CDR and implications for sustainable development. For the AR6 as a whole the possibilities are much broader, and thus require more thought from the beginning.
- Kate Calvin: While there are challenges to using scenarios to integrate across working groups, it still is worthwhile to pursue
- Katja Frieler: The integration across working group is a great opportunity. There are still many challenges and inconsistencies in the use of scenarios, but also options to solve at least some of this if we use the time window we have.
- Vanessa Schweizer: Acknowledged the efforts of the Working Groups, as the plans for utilizing scenarios in AR6 look much more cohesive than what has come before. Nevertheless, there is always room to do more and to do better. A frontier to address is how to use AR6 as a vehicle to mainstream scenario thinking amongst knowledge users outside IPCC.
- Brian O'Neill: Scenario-based storylines are promising as a way of synthesizing results across working groups.

Hoesung Lee (IPCC Chair):

- Thankful of the discussion and idea to develop a storyline for the SYR
- We need to develop storyline strongly anchored to science and to society
- We need to pay close attention to near-term action and transition. What are the barriers to up-taking short-term actions?
- Transition: How to accelerate the transition to a desired pathway. We seem week at this point on the driver that can help the society move to climate-resilient pathway.

Overall summary of the session:

- SSP-RCP framework greatly contributed and facilitated scenario assessment in SR15
- Logistical challenges related to coordination across IPCC reports Data availability, literature cut-off dates). By using the time window will still have for xWG coordination we can improve consistency, relevance quality etc across reports.

- Challenges with using scenarios: Comparing across models, studies, and regions, choosing scenarios, collecting information, difficult to find scenarios that cover many aspects, e.g., SRCCL
- What relevance is given to socio-economic assumptions in WGII? Critical to synthesize WGII and WGIII results in terms of avoided climate impacts due to a mitigation pathway
- Scenarios as integrating element across reports (SR, WGs) and can play an essential role for real synthesis in SyR (i.e., not a summary of SPMs). This has implications for ongoing SR and WG work and close collaboration is essential
- How can we systematically feedback experience from AR6 process to the scenario community? Expert meeting? Timing: End of AR6 cycle; after SyR?
- More efforts needed in communication of results from RCP-SSP framework
- Openness of data is essential to allow new communities to tap into this resource before and during the assessment process

## Migration

Session title: Climate-induced migration: applications and enhancements of the SSP framework

Session organizer(s): Bryan Jones (CUNY), Jacob Schewe (PIK)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

Migration, in particular the impact of climate and societal change on migration patterns is a challenging area of study as (1) it is very difficult to disentangle the diverse factors that drive the migration decision and (2) projecting migration flows into the future has always been a somewhat uncertain endeavor, in no small part because it is so difficult to unpack the drivers. All that said, the potential for climate change to impact migration is of substantial interest to many communities, and the researchers are responding to the demand for more information. The SSP/RCP framework is becoming more widely used in the study of both internal and international migration, this session was designed to touch on advances in both areas. Highlights included:

- The development of SPAs for adaptation to sea level rise on the Mediterranean coast, and application in a high-resolution coastal impact and population model from which estimates of SLR-induced migration can be developed.
- The projection of future international migration flows and their impacts on inequality under the SSPs using a two-sector overlapping generations model
- An agent-based model of internal migration trained on, among other factors, cell-phone data in Bangladesh designed for application to RCP/SSP-based projections of sea-level, coastal storm surge, and socioeconomic/demographic change. The model is designed to address short-term/temporary movement, long-term migration, and the development of trapped populations, an important development in that most existing models focus on only one type of mobility/immobility)

- An econometric approach emphasizing the role of GDP in the “net migration transition”.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

- The SSP storylines generally proved very useful by providing a widely applicable, unifying scenario basis.
- The quantitative GDP and population scenarios were widely used and did prove useful, though it sometimes became clear that there is potential for improved or alternative quantifications, and the existing quantifications may constrain further research if used too dogmatically.
- Because international migration is included in the national population projections corresponding to each SSP, it is unclear how best to proceed with estimating the impacts of climate change on international migration under the SSP-RCP framework. More discussion on this topic is necessary so that best practices can be developed.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

- Additional thought regarding the effect of the SSP framework on estimates of future migration would also be useful. One presenter suggested that; “with SSPs as forcing functions, there is limited potential for migration to have transformative effects in the model (either for good or for bad) because the conditions imposed by the SSPs act as bumpers”. The degree to which this statement is true is not yet clear, nor is it clear whether the comment applies across different modeling approaches. Nonetheless, it is useful to step back and consider the implications of adopting the SSPs in models of future migration – we hope this conversation will continue.
- Because patterns of urbanization are considered in the SSPs (rates in the core SSPs and spatial patterns in existing subnational projections), some level of internal migration is implied. Better developing the qualitative assumptions regarding economic transitions and internal migration would be useful in guiding future attempts to quantify internal migration.

*What are other key highlights from your session?*

- The use of a large cellphone data set for estimating the migration response to cyclone landfall in Bangladesh. (Research yet inconclusive but promising method.)

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

- Both researchers and (national/international) policymakers would benefit. Local policymakers and practitioners might benefit to some extent, potentially limited by lack of spatial detail.
- Migration can be studied across multiple spatial scales, the SSPs provide a framework that can, potentially, unify work conducted across scale such that the local context may be better integrated with national and international trends (and vice-versa). Planners/policymakers across multiple levels of governance will benefit from a more rigorous understanding of how migration processes operate across and between scales as a more coordinated approach to policy becomes possible.
- In today's political environment, it is important to take an objective approach to migration such that we might better understand when and where migration makes sense as an adaptation strategy, and should therefore be encouraged. Not all migration represents a "crises"!

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

- The World Bank is following up on the 2018 Groundswell Report with several country/regionally specific follow-up studies. An enhanced version of the original model is planned tailored to meet the needs of stakeholders.
- PIK (Germany) and CUNY (US) are collaborating to model climate-related migration across spatial scales (IMPETUS project). Specifically, this involves developing a dynamic model for international migration, extending the NCAR-CIDR spatial population model, and exploring the interaction between them.
- The Earth Institute at Columbia University is hosting a 3 day event entitled "At What Point Managed Retreat? Resilience Building in the Coastal Zone".
    - http://adaptation.ei.columbia.edu/conference/at-what-point-managed-retreat-conference/

## Multi-scale Scenarios

Session title: Extending the SSPs across space and time: Multi-scale scenario development practices

Session organizer(s): Kasper Kok (Wageningen University) and Benjamin Preston (RAND Corporation)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The two sessions on extending the SSPs demonstrated three clear trends in how the SSP framework and the associated storylines and quantitative scenarios are being used. First, as evidenced by the sessions themselves, is that the SSPs are being used to explore climatic futures at a range of geographic scales. This suggests that the framework has successfully

transitioned out of the integrated assessment modeling community as is finding traction in a broader, more diverse community of global change researchers and practitioners. Second, the SSPs are being applied to explore development and climate futures in specific sectors, with presentations from the sessions focusing specifically on the energy and agriculture sectors. Third, multiple presentations illustrated how the SSPs are being used at the local level as a tool for helping community stakeholders develop and test alternative visions of the future of their communities. While using scenarios to articulate normative, attempts to use the SSPs in this manner represents a notable expansion of application beyond their original design.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

The two sessions revealed two key tensions in the use of SSPs. The first was related to the question of internal consistency in SSPs storylines and assumptions across scales. Specifically, a number of the session presentations involved the use of the SSPs with local communities, which raised the need to engage with what are largely global storylines at a local level. This raised questions of methods for using the SSPs at local scales (i.e., how to translate the global to the local) as well as how to maintain internal consistency in the process. A recurring debate was the importance of internal consistency in the use of scenarios (with multiple references to Zurek and Henrichs, 2007). While such consistency may indeed be important for some multi-scale applications of the SSPs where explicit connections exist across different geographies and scales (e.g., transnational climate impacts), for others, efforts to maintain consistency may simply be an unnecessary distraction. For example, when using the SSPs to engage local communities in developing visions of the future, connections to higher scales may be of little importance. Given the SSP framework was designed to be flexible to a range of uses, efforts to compare within or among SSPs (e.g., some form of metaanalysis) may be useful.

The other apparent tension that emerged was between researcher understanding of the SSPs and the conceptual framework and those of external audiences such as stakeholders or climate practitioners. Several presentations during the sessions noted the challenges of communicating the SSPs to community groups. This was attributed in part to non-intuitive labels (e.g., “SSP1”) for the various storylines and the fact that the SSPs were developed for the purposes of analysis of the future, but not communication about the future. In addition, some presentations noted a reluctance of some individuals to engage with scenarios they feel are counterproductive or controversial, which was often a function of tensions between positive and normative interpretations of the SSPs. For example, SSP5, with its emphasis on fossil fuel-driven growth was rejected by some community members because that development pathway was inconsistent with the community’s vision of itself. In addition, there tended to be anchoring on SSP2 as a balanced, middle-of-the road scenario (which is perhaps interpreted as a most likely scenario).

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

Given the SSPs are now being used by a diverse group of researchers and practitioners, giving additional consideration to what should be in the SSP “toolbox” to best enable such diverse

uses might be useful. For example, including guidance and tools for using the SSPs to engage communities might help to overcome some of the challenges identified in the sessions in this regard. In addition, developing a formal process for revisiting, refreshing, and/or reforming the SSPs on a regular basis can help maintain their relevance to current policy and analysis needs.

*What are other key highlights from your session?*

A topic of discussion during the sessions was the potential value of developing “official” socioeconomic storylines and scenarios that are sanctioned by particular organizations or governments. For example, is their value in having EU-specific versions of the SSP storylines and scenarios that could be commonly used by researchers and practitioners throughout the region? While this could assist with embedding the SSPs in global change research, there is the potential for resistance to giving the SSPs such official status and raises questions regarding whether this would undermine the original intent which is to build a flexible framework that can be creatively adapted as needed by users.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

Based on the presentations, the sessions were likely most beneficial to those working at local to regional scales (i.e., cities and local governments to states/provinces and subnational geographic divisions. This includes both researchers conducting work on sectoral or integrated analysis of climate change impacts, risk and adaptation as well as those working at the local level with communities and practitioners to develop local plans and visions for climate action.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

No specific plans for follow-up activities have been decided. However, one potential niche could be a special issue on the use of the SSPs in local-to-regional scale global change research and assessment.

## Nitrogen

Session name: New nitrogen scenarios using the SSPs

Session organizer(s): David Kanter (NYU), Wilfried Winiwarter (IIASA)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The lack of nitrogen-specific policies in the SSP-RCP framework consistently results in little improvement in terms of nitrogen impacts on the environment. As a consequence, advances in this topic area have focused on the development of specific policies and measures to tackle nitrogen pollution within the SSP-RCP framework.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

The SSP-RCP framework provides key information regarding overarching trends related to population, technology development etc. and links to related work on land-use, energy, wastewater etc. that are all relevant to future nitrogen pollution trends. A subset of the SSP-RCP combinations are often selected in studies to represent the range of potential future nitrogen trends. However, the imposition of new nitrogen-specific measures and policies has the potential to feedback into the original SSP-RCP storylines (e.g. related to diet, bioenergy etc.) and thus lead to inconsistencies. Furthermore, in the current framework it remains questionable whether even the most ambitious mitigation scenario in a world commited to sustainable development will be sufficient to return to the planetary boundary for nitrogen and phosphorus. A solution to that problem may be a backcasting approach – possibly with repercussions fors core SSP-RCP issues, i.e. not being able to meet certain climate goals.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

Food scenarios and consequently land use scenarios targeted on low nitrogen consumption.

*What are other key highlights from your session?*

See session summary, below.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

Our research is meant for implementation. So while we look to other researchers for input and collaboration, policy makers, environmental interest groups, and the general public are our main audience.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

Some of the work presented in this session has been published or submitted for publication. There is potential for a joint publication of an overarching paper, which will depend on the near-term activity level of the audience.

**Nitrogen Session Summary**

The goal of the nitrogen session was to better understand the ongoing work using the SSPs to explore regional nitrogen futures and the potential links with a new set of global nitrogen storylines.

The first three talks presented nitrogen input estimates for the EU, US and Baltic region, respectively, based on a subset of RCP/SSP combinations representing best- to worst-case outcomes. In each case, relevant RCP/SSP inputs developed at the global scale – from crop yields to fertilizer inputs – were integrated within regionally focused models. Several key drivers of future nitrogen flows were common across all presentations: namely diets, food waste, and bioenergy production. The magnitude and distribution of future nitrogen flows in these regions and others will be heavily dependent on these drivers, suggesting that certain measures to limit climate change (such as increased bioenergy) may be inconsistent with a world committed to less nitrogen pollution. In addition, global trade flows could limit the environmental benefits of nitrogen policies, because a national policy to, for example, limit meat consumption to reduce nitrogen losses could be offset by increased meat exports to meet increasing demands across the rest of the world.

What also was clear from each presentation is that SSP/RCP combinations alone do not represent the full spectrum of possible nitrogen futures, and that additional nitrogen-specific policy interventions are required. In the case of the EU, these additional interventions were added with a focus on more stringent nitrogen standards and improved diets (beyond what is currently considered in the SSPs). Instead of evaluating specific policy instruments, they associated different RCP/SSP combinations with different carbon prices as a proxy for achieving their policy goals. For the Baltic Sea region, the main nitrogen impact of concern is eutrophication. Researchers there also extended the RCP/SSP combinations to better reflect local conditions. It was clear from this analysis that even the most ambitious RCP/SSP combination suggested no change in current policy, again implying that more stringent nitrogen-specific interventions may be necessary. The investigation of eutrophication impacts in the U.S using the RCP/SSP framework indicated nitrogen losses ranging from a stark increase to little decrease by mid-century, again suggesting that this framework is limited in helping to understand the full scope of possible nitrogen futures.

At the global level, additional nitrogen-specific interventions have been developed under the framework of the UNEP-funded International Nitrogen Management System (INMS). They focus on, among other factors, improving crop and livestock NUE and changing consumer diets. These activities were introduced in the final two presentations of the session. The interventions are separated into high, medium and low policy ambition. High ambition represents the frontier of technical feasibility in a timeframe largely consistent with the Sustainable Development Goals, which run until 2030. Moderate ambition reaches the same frontier over a longer time horizon (2050 or 2070), while low ambition represents either no improvement or a continuation of current trends. Given country differences in economic and agronomic circumstances, three country groups are defined by their economic wellbeing and N use intensity, with three corresponding sets of N policy trajectories: OECD countries, non-OECD countries with moderate to high N use (defined as an N surplus greater than 50 kg N $ha^{-1}$, e.g. China), and non-OECD countries with low N use (N surplus less than 50 kg N $ha^{-1}$, e.g. Tanzania).

Several stages of stakeholder engagement allowed for the co-development of global nitrogen narratives within the SSPs. The first step of this engagement was in January 2018, when stakeholders from international organizations such as UNEP and OECD were part of the first INMS nitrogen scenarios workshop. Their input on focal points, timescales and indicators were integrated into narrative development. The next step is to downscale these global storylines to regional scales, which requires further refinement of priorities based on regional stakeholder input. This was recently done by engaging with nitrogen scientists across regions via a questionnaire. While the feedback made clear the priorities at these scales, more work needs to be done to integrate the SSP/RCP framework within pre-established national pathways.

From all the presentations it became clear that the SSP/RCP framework alone is insufficient for depicting a world without excessive nitrogen pollution. Further N-specific measures are required. These need to take trade issues into account so that the separation between the useful outcome of nitrogen application (i.e. foodstuffs) and its environmental consequences (pollution) is explicitly considered. Involving stakeholders may in many cases be helpful in order to provide joint ownership of results and thus make the implementation of measures more likely. However, if stakeholders or scientists have pre-established notions on what a nitrogen future may look like already set in stone, then this may make moving the scenario process forwarded very difficult.

Finally, we should accept that additional interventions within the SSP/RCP framework may not be sufficient to meet certain nitrogen-relevant environmental thresholds (as described in the planetary boundaries literature, e.g. De Vries et al 2013) and approaches such as backcasting might need to be explored to work back from specific targets to develop achievable pathways.

## Oceans

Session name:  Scenarios for the Future Ocean

Session organizer(s): Tyler Eddy (University of South Carolina), Jörn Schmidt (University of Kiel), Alan Haynie (NOAA), John Pinnegar (CEFAS)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

- There are a number of groups currently adapting the SSP framework for fisheries, shipping, and oceans projections under climate change:
    - CERES in Europe – fisheries and aquaculture modelling
    - ACLIM and SICCME in Alaska – fisheries modelling
    - Arctic Marine Shipping scenarios
    - Nereus Program global IAM scenarios
- Local, regional, and global scale scenarios being developed

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

- Challenges to contextualize the SSPs to ocean related activities

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

- More consideration of interactions between land-based and ocean activities

*What are other key highlights from your session?*

- A lot of interaction with stakeholders on local and regional scales
- A small but growing community working on future ocean scenarios

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

- Audiences for local and regional sectors: fishing and aquaculture companies, shipping and Regional Fisheries Management Organizations, regional policy makers
- Global audiences are: IPCC, IPBES, World Ocean Assessment, IOC-UNESCO

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

- There is an IPBES scenario workshop taking place at UBC, Canada from March 25-29, 2019 to develop scenarios that include oceans
- There is a future ocean scenarios workshop and session at the IMBeR Future Ocean meeting in Brest, France taking place from June 15-21, 2019
- There is a FishMIP (sector of ISIMIP) scenarios working group that has been setup to translate SSPs into future fishing scenarios that will be hosted by FAO in 2019
- There is a conference about marine socio-ecological systems (MSEAS) taking place in Yokohama, Japan from May 25-29, 2020

## Overshoot

Session title: Overshoot scenarios for Paris Agreement temperature targets: an interdisciplinary perspective

Session organizer(s): Katsumasa Tanaka (NIES), Johannes Bednar (IIASA), Oliver Geden (German Institute for International and Security Affairs, Max Planck Institute for Meteorology), Daniel Johansson (Chalmers University of Technology, Sweden), Michael Obersteiner (IIASA), Kiyoshi Takahashi (NIES)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

- The SSP-RCP quantitative emissions scenarios developed with IAMs have been an object of analyses for the overshoot-related studies, not so much inputs of the analyses. i.e. the scenarios with radiative forcing / temperature overshoot scenarios are picked up from the pool of the SSP-RCP emission scenarios and their characteristics (e.g. a peak timing, energy mix, dependency on BECCS etc.) are investigated.
- Some studies estimate cost-effective emission pathways considering maximum temperature increase constraint with some assumption on overshoot. However, the socio-economic assumptions (technology improvements, population, etc.) published in the (baseline) SSPs have not been necessarily taken as a baseline for the analyses.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

- The SSP-RCP emission scenarios database is basically an important resource for overshoot analyses.
- However, the combinations in the current SSP-RCP matrix considered may not be enough for analyzing various aspects of (temperature) overshoot. Among them, SSP5-RCP3.4 (and climate model projections based on it would be useful with the largest negative emission required.
- The time horizon of the current SSP-RCP scenarios (until 2100) is also a limitation for some types of analyses (e.g. analyses of irreversible impacts, analyses of relatively long duration of overshoot period).

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

- Extension of the SSP scenarios beyond 2100
- Better representation of non-CO2 gases
- Differentiated development of scenarios for supporting (near-/mid- term) policy analyses and scenarios for supporting (very long-term) natural/biophysical analyses.

*What are other key highlights from your session?*

We emphasized the interdisciplinary nature of the session from the onset. We were able to gather diverse perspectives for overshoot pathways: perspectives from natural science, economics, and political science. We realized that the participants were also diverse. As one of the highlights, we note that it was useful to hear about the experience of an author for the IPCC SR15, who had communicated overshoot scenarios with policymakers.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

We hope that each participant gained something from our session, but we also hope that those who evaluate the needs to include more overshoot scenarios in the SSP-RCP scenario framework most benefited from our session since we intended to provide input to this direction. As indicated by the first invited talk, there is just one overshoot scenario within the current SSP-RCP (i.e. SSP5-RCP3.4, an overshoot of about 0.4 °C). Presentations that follow showed various overshoot scenarios with different length and magnitude, not represented by SSP-RCP. These scenarios are generated either under a set of simpler assumptions or by internal model calculations without aligning to SSP-RCP. These variety of overshoot scenarios may provide a fertile ground for future analyses, especially for questions related to earth system reversibility/feedbacks, carbon budget, transient impacts, and geoengineering. Such analyses typically require overshoot scenarios for a long period of time (i.e. till 2150 or longer). However, Integrated Assessment Models used to generate SSP-RCP scenarios are not usually set up to produce scenarios beyond 2100. A gap has been thus identified between what can be readily offered and what may be desired for the future. This suggests that the future SSP-RCP development could address this gap to extend the area of scenario applications.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

We, all six conveners as well as a few session participants, have agreed on a plan to develop a perspective paper mapping out issues related to overshoot scenarios. Some of the conveners have started preparing a paper outline through a Skype meeting prior to the Forum (December 2018). After the session, we got together and continued discussion by listing issues that had been touched upon during the session as well as complementing issues that had not been raised. We will put them together and work jointly to write up a paper for the next several months to come.

Furthermore, the convener Katsu Tanaka will start a three-year project focusing on the analysis of overshoot scenarios later this year in France. The discussion in this session and the paper in preparation will be a useful input to (and a basis for) this upcoming project. We may collaborate further under this project.

## Regional climate

Session title: Climate change scenarios in CORDEX domains

Organizers: Cecilia Conde, chair (UNAM, Mexico), Tereza Cavazos, chair (CICESE, Mexico), Landy Sánchez (El Colegio de México)

The COordinated Regional Downscaling EXperiment (CORDEX), implemented under the auspices of the World Climate Research Program (WCRP), aims to improve downscaling (statistical and dynamical) simulations and future scenarios and their use in the provision of robust regional climate information for application in vulnerability, impacts and adaptation. In the context of the Scenarios Forum 2019, one of the challenges of the CORDEX community is to enhance the collaboration with the impact and integrated assessment communities to use and

evaluate SSP-RCP scenarios at regional and local scales. In our session, Melissa Bukovsky from NCAR (our second invited speaker) presented preliminary results on SSPs for climate change and land use cover change (LULCC) in the United States. These were the only results presented that used the SSPs, underscoring the need for CORDEX to promote using SSPs in its program.

Most of the CORDEX community has been involved in developing RCP scenarios for different domains in the world from 50 to 20 km spatial resolution, but very little advancement has been done on SSP-RCP scenarios. We believe the NCAR group is at the forefront of this initiative, but there might be isolated studies in Europe, which we will try to identify in our next international meeting in China. CORDEX Co-chairs Silvina Solman and Bill Gutowski participated in our session, and they took note on this important challenge, which needs promotion at the CORDEX-wide meeting in October 2019 in Beijing, China.
The lack of progress of SSP-RCP joint scenarios is because this has not been an objective in CORDEX. CORDEX has expected the impacts and integrated assessment communities to use its fine scale projections under different RCPs to produce interdisciplinary projections that could feed into SSP-RCP usage in impacts models. But, after this meeting information about the SSPs will be passed on to the CORDEX members and users, urging them to explore the implications of SSPs for each CORDEX region's climate.

The key highlight from our session is that we had participants from several CORDEX domains and that the CORDEX-North America group is already developing SSP-RCP-driven climate simulations and analyses. The audience of our session was intended for different groups from academia to interdisciplinary scientists and government users.

Follow-up activities related to this CORDEX session are:
1) Paper-writing Workshop on the Analysis of CORDEX-CORE Climate Projections. ICTP, Trieste, 8-12 May 2019.
2) ICRC-CORDEX 2019: International Conference on Regional Climate-CORDEX 2019 will take place on the 14th-18th October 2019 in Beijing, China. This conference will promote the CORDEX vision to advance and coordinate the science and application of regional climate downscaling through global partnerships. As a result of the Scenarios Forum 2019, CORDEX co-chairs will recommend the development of SSP-RCPs scenarios during this year's ICRC-CORDEX meeting.

## Scenarios and assessment

Session title: Scientific assessment of scenario-based research

Organizers: Vanessa Schweizer (University of Waterloo)

The session spanned assessment topics across multiple levels of scenarios analysis using the SSPs. These included validation of reference scenarios realized by a single model (Binsted), expectations across disciplines for how model validation should be done (Eker), philosophical issues for the SSPs such as ontology (Foster) and their performative effects on policy

discussions (Low), and (semi-)automated literature retrieval for scientific assessment of multidisciplinary research using the SSPs (Schweizer).

Notable advances related to scenario/model/literature assessment included development of simple but useful visual analytics for validating a reference scenario (Binsted) and a scientometric approach (citation networks) for retrieving and classifying multidisciplinary SSP research. However, these advances do not have direct implications for using or further developing the SSP-RCP or other scenario frameworks.

Two features of current SSP-RCP literature 'hindered' progress on automated literature retrieval for scientific assessment. First, as exciting as the proliferation of research is using the SSPs, there may not yet be a critical mass of SSP-RCP scholarship that lends itself to being identifiable through machine learning. Second, SSP-RCP studies will always contain language similar to other climate change research not using the framework. This suggests that machine learning alone as an automated literature retrieval approach may not be able to distinguish SSP-RCP literature from broader climate change research. In anticipation of a larger literature that may benefit from (semi-)automated approaches for sorting, work is ongoing for coupling machine learning to scientometric approaches (i.e., a citation network with community detection).

None of the presentations or discussion suggested that the scenario framework needed key modifications, additions, or extensions to be helpful for future work on scenario/model/literature assessment.

Other key highlights:

- Discussion of the tension between modelling for insight (i.e., exploration, "map making", broadening the suite policy options) and the performative effects of model results on policy discourses (i.e., setting agendas, deciding what goes on the map). No conclusions were drawn.
- Discussion of different approaches to model validation. Eker's presentation contrasted data-driven approaches (e.g. hindcasting), the fit-for-purpose criterion, and complementary criteria for decision making under uncertainty (narrative coherence of scenarios, robustness of system performance to alternative scenarios, adaptive strategies). Discussion focused on tensions surrounding data-driven validation in particular. It was recognized that hindcasting can be useful for establishing the credibility of a model; however, there is the risk that the past is no longer a reliable guide for the future (especially for modeling studies extending 30 years or more into the future). Eker acknowledged that the data-driven paradigm for validation is dominant but suggested that this should not be the only game in town.
- Discussion of what literature gets scientifically assessed. Schweizer's presentation focused on papers in Web of Science. Papers in other languages were raised, which may have different cultural perspectives on scenarios or the future. How well these alternative literatures might be covered in IPCC scientific assessments was unclear.
- Discussion of how "feasibility" and "desirability" are understood across disciplines. Low's presentation contrasted the modeling definition of feasibility (whether or not the model can

find a solution) with non-modeling definitions (e.g. technological feasibility, political feasibility). “Desirability” was not expressly discussed. This suggests that feasibility and desirability may be muddled concepts in policy discourse. No conclusions were drawn about how this should be addressed.

Audiences (researchers, practitioners, policymakers) that might benefit most from the scenario-related work in this session: modelers, scientists/researchers making use of or developing scenarios, scientists/researchers authoring scientific assessments.

No plans for follow-up activities (meetings, publications, projects, etc.) expressly on the topic of assessing scenario-based studies were mentioned during the session. However, outside the session, the April 24th CICERO workshop on physical modeling supporting a “storyline approach” was mentioned (https://www.cicero.oslo.no/en/publications-and-events_twex/workshop-on-physical-modeling-supporting-a-storyline-approach). Related overlapping questions include:

- How can storylines or narratives of specific events be combined with probabilistic approaches?
- What are the challenges and advantages of this storyline approach (basically picking a particular event) compared to the full probabilistic approach? And how does it differ or compare with other storyline approaches (e.g. SSPs)?
- What are useful approaches to combine physical with statistical modeling and the knowledge from other domains (e.g., social sciences, impact modeling)?

## Scenarios as Service

Session title: Scenarios as service

Session rganizers: Robert Lempert, RAND, USA; Henrik Carlsen, Stockholm Environment Institute, Sweden; Celine Guivarch, CIRED, France

This session explored new quantitative methods for extracting insights from large scenario ensembles that might build on the RCPs and SSPs to provide an even richer set of policy-relevant information. The decision support literature distinguishes between products and services. The former includes tangible deliverables, such as the RCPs and SSPs, while the latter include interactions that enable better use of decision relevant information. The so-called ‘scenarios as service’ concept envisions providing large databases and decision tools to allow users to craft scenarios fit for purpose while maintaining consistency and comparability across users provided by the current ‘scenarios as products.’ The session covered conceptual and methodological approaches, as well as lessons learned from empirical testing of how scenarios are used in practice by the expert and non-expert stakeholders.

The talks demonstrated recent advances in each of these areas. Jonathan Lamontagne, Tufts University, USA discussed work in which “scenario discovery” classification algorithms were used on a large database of roughly 40,000 GCAM runs to identify scenarios, similar in many respects to the SSPs but with different policy implications. Using such methods, regional and

sectoral stakeholders could evaluate a broader array of potential scenarios and choose those most appropriate for their particular decision needs.

Henrik Carlsen of the Stockholm Environment Institute, Sweden described IAP2, an interactive, web-based modeling platform that includes meta-models for a variety of interlinked sectors and captures cross-sectoral interactions. The system combines RCPs, SSPs, and different combinations adaptation measures to identify situations in which combinations of adaptation measures can provide synergies, that is effects greater than the sum of their effects, or interference, that is effects less than the sum of their effects.

Steve Arquitt of the Millennium Institute presented the Integrated Sustainable Development Goal (iSDG) model, a systems dynamics platform that enables participatory development multi-sector models to chart pathways for meeting Sustainable Development Goals in developing countries.

Evelina Trutnevyte, University of Geneva, Switzerland presented the results of an experimental study in which non-expert participants could either explore large scenario databases or interact with a small number of static scenarios. The experiment found that the ability to explore the large databases did not provide measurable advantage over the static version on the engagement, knowledge gain or trust of non- expert users. In fact, the users extracted the needed information from the static scenarios with storylines statistically significantly better. The experiment suggests that interactive web-tools may not be a panacea for the scenario visualization from energy, integrated assessment and environmental modelling.

Overall, this session pointed to an increasingly rich set of methods and tools for identifying and using policy-relevant scenarios as well as the importance of empirical research in learning how to best use scenarios to provide effective decision support.

## Short-lived Forcers

Session title: The role of short-lived climate forcers in future scenarios

Organisers: Jan Fuglestvedt (CICERO), Detlef van Vuuren (PBL)

The session started with a brief introduction of the organisers indicating the importance of short-lived climate forcers (SLCFs) - such as aerosols (and their precursors), HFCs, $CH_4$ and ozone precursors. SLFCs form a group of components with very different atmospheric and climate properties than $CO_2$ . Another important characteristic of some SLCFs is that they are subject to relatively large uncertainties in estimates of their climate effects. The role of SLCFs in mitigation scenarios can be important especially in the short-term. Moreover, many SLCFs are also air pollutants thus providing options for both synergies and trade-offs. As a result, the future development of SLCFs, their effects and the implications for mitigation strategies are very relevant for climate research.

The first speaker, Mathias Weitzel, looked into mitigation strategies that considered in addition to $CO_2$, also SLCFs. For this, the emissions of non-$CO_2$ greenhouse gases (GHGs) were included in an economic model (CGE). This can be done by different activities, but also by a hybrid method including “end-of-pipe” measures with discrete abatement technologies and specific abatement functions per pollutant, sector, region and year. The results show that including non-$CO_2$ can lead to a reduction of mitigation costs, as reported also by EMF-21.

The second speaker, Rita van Dingenen, presented the TM5-FASST tool that provides a screening tool for the impact of reducing non-$CO_2$ emissions on climate change and air pollution. Impacts that are included are human health, crop yield impacts, N/S deposition and climate metrics. The screening tool is based on so-called source-receptor matrices that emulate the results of detailed models. The advantage is that the tool is computationally efficient and can thus be used in models looking into mitigation strategies. The tool has been used in several projects, including the SSPs.

Steve Smith did discuss the implications of SLCF uncertainties for future scenarios. He specifically paid attention to warming in the Arctic. For this, he used a scaling method in combination with a simple climate model. The model showed the importance of black carbon and sulphur emissions for artic warming, but there is a large uncertainty (the size of the artic amplification is the largest uncertainty, but aerosol forcing is also important). Recent research shows that BC forcing and temperature response might be smaller than considered so-far. He noted, however, that impact of BC can still be large for other variables such as wind fields and the East Asian Monsoon.

Bill Collins started off with the fact that the SSPs has a larger spread than the RCPs for air pollutants – which makes them more useful for research on air pollution and SLCFs. Air pollution policies are also handled more transparently in the SSPs. Based on the SSPs, AerchemMIP formulated a set of scenarios to research the contribution of SLCFs. Collins explored the progress being made to quantify the overall effects of short-lived climate forcers through understanding how their forcing patterns induce rapid adjustments in meteorology either amplifying or dampening the forcing; and how these forcing patterns lead to temperature changes that may have a different climate sensitivity than that for $CO_2$. Bill Collins subsequently started a discussion on the use of $GWP_{100}$ for methane indicating that in his opinion they should not be used. Others, however, had a different opinion and indicated that $GWP_{100}$ might be an acceptable compromise.

Zigniew Klimont showed how mitigation of BC can lead to health benefits, focusing particularly on Asia. A set of top-25 mitigation measures could provide clean air for a billion people. There could also be a positive impact on warming – depending on the type of measures. Recent work of IIASA also highlights the importance of consistency in reduction assumptions (e.g. between BC and $CH_4$). He also pointed out that so far there has been most focus on $CH_4$ while implications for $NH_3$ emissions and feedbacks from $NH_3$ mitigation options on $CH_4$, $N_2O$, NOx are often not accounted for in models.

The presentations highlighted the importance of the SLCFs in long-term scenarios. There is also quite some room for further research:

- Reducing uncertainty in emissions and forcing of aerosols, and the following climate response
- Explicit consideration of mitigation costs for air pollutants in IAMs
- Consistent assumptions for different SLCF mitigation measures
- Better considerations of health impacts – which would mean more explicitly dealing with PM2.5 (not currently included in SSPs).
- Finding ways to quantify the impact of SLCFs on carbon budgets.

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The SSP/RCP framework has put the focus on all kinds of uncertainties related to development, including air pollution. As a result, the framework covers a much wider range for SLCF emissions than the RCP scenarios. Subsequent on scenario analysis shows the possible synergies in reducing SLCFs for both forcing and air pollutants. The contribution of aerosols could to reducing warming, however, be relatively small given the recent estimates of BC forcing and also the reduction of BC emissions in baseline and mitigation scenarios without a specific additional focus on BC.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

The explicit focus on the SSP-RCP framework on development and thus air pollution policy was helpful. At the moment, however, the coverage of SLCFs needs to be developed further. In IAMs the focus has been mostly on climate impacts. As a result, several IAMs include BC, but PM2.5 (relevant for health) is not explicitly included. Also the costs of air pollution control is often not included.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

See end of the summary above.

*What are other key highlights from your session?*

A key factor is all presentations was uncertainty. An interesting discussion emerged on how to best compare different gases in the context of climate policy.

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

All

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

There were no specific activities discussed. EMF30 is still being finished. Several IPCC authors (WGI and WGIII) took part in the discussions which were very relevant for the IPCC Assessment reports they are writing.

## SSP Extensions

Session name: Extending the Shared Socioeconomic Pathways for Impacts, Adaptation, and Vulnerability research

Session organizer(s): Lena Reimann (University of Kiel), Athanasios T. Vafeidis (University of Kiel), Bryan Jones (CUNY)

The session dealt with a range of qualitative and quantitative extensions of the SSP-RCP scenario framework to enhance the basis for IAV assessments. One presentation discussed barriers to adaptation and pointed out the need for differentiating sector-specific barriers under the SSPs. Elements consistent with the SSPs such as GDP, education, the Human Development Index, inequality, governance, and gender inequality can be combined to calculate indices of adaptation and adaptive capacity. With the help of these indices, changes in adaptive capacity, barriers to adaptation, and potentially resulting losses and damages can be assessed. Furthermore, two talks presented spatially explicit datasets of important vulnerability indicators downscaled from the SSP national-scale projections: poverty in urban versus rural areas for the entire globe; and population per age group, sex, and race on a U.S. county level. These data can serve as a basis to assess exposure of vulnerable population groups at regional to global scale. Two additional studies applied different downscaled projections of the SSPs to assess exposure and vulnerability at sectoral level (i.e. coastal, heat-related stress) and at regional to local level (i.e. Europe, Houston). Both studies found that the use of downscaled projections of indicators such as population, age, and education constitute an important step forward in enhancing IAV studies under a range of SSP and RCP combinations.

In this session, we established that the SSP narratives provide a solid basis for extending the SSPs for IAV-related assessments. The narrative elements are broad enough to allow interpretation for a vast range of extensions (e.g. coastal, heat-related, adaptation barriers, poverty). Such extensions are urgently needed for characterizing impacts and vulnerability, while also accounting for disruptions (e.g. conflict, depression) in the SSP narratives. Further, the national-scale projections of key indicators (e.g. GDP, urbanization) serve as boundary conditions to producing downscaled projections at subnational scale. However, we found that few downscaling exercises explicitly describe how they interpret the narratives and/or specific narrative elements to produce downscaled projections. In order to be able to compare downscaling exercises with each other, describing in detail the step from narrative to

quantification is crucial. Next, we found that the methods discussed in this session are widely applicable, also in data-scarce locations. This is an important criterion for IAV assessments, as the most vulnerable countries are in many cases also data-scarce countries. Additional extensions of the SSP framework and projections are needed to downscale further metrics to characterize vulnerability and adaptive capacity to a wide range of climate impacts. The metrics needed for such extensions (e.g. age structure, education, HDI) largely depend on the specific application (e.g. flooding, heat stress, food security) and on the spatial scale (i.e. global, regional, national, local). Also, further work is needed on how different spatial scales can be captured in the SSP narratives.

Furthermore, the session showed that the scenario matrix architecture constitutes a very useful tool in exploring the range of uncertainty regarding different climatic and socioeconomic conditions. The matrix allows for teasing out the effects of climate change versus socioeconomic development regarding the impacts of climate change. All of the studies presented found that the contribution of socioeconomic development on climate change-related impacts is comparable to the climate signal, if not higher. Consequently, studies conclude that socioeconomic modeling aiming at characterizing vulnerability and adaptive capacity should receive similar attention to climate modeling, which has not been the case in previous research. Similarly, reduction of vulnerabilities and increase in adaptive capacity are as much needed as the mitigation of climate change.

We envision different audiences to benefit from the advances discussed in this session: researchers can use, apply, and further extend the established IAV indicators to assess vulnerabilities to a multitude of climate change-related impacts under a range of socioeconomic futures. Subsequently, these results can be communicated to policymakers as a basis for adaptation planning and for establishing policies to reduce vulnerabilities and increase adaptive capacity, accounting for the range of uncertainty regarding future socioeconomic development. Furthermore, practitioners can use the spatial data and study results, particularly at the local scale, to implement specific measures such as where to install retention areas to hold back flood waters or where to establish parks to mitigate heat stress that are effective under a range of socioeconomic futures.

At the end of the session, the need for a separate meeting solely focusing on SSP extensions for IAV research was raised. Such a meeting would pursue the goal to harmonize the process of extending SSP-based projections of different metrics to characterize vulnerability at different spatial scales, and for a range of different applications. It would be particularly helpful to coordinate extension/downscaling exercises taking place in the European and the U.S. context to reduce redundancy regarding similar research questions and goals. In this context, establishing a database of publicly available data based on the SSP framework for characterizing climate change-related vulnerabilities would be an important step forward.

### Subnational

Session title: Sub-national scenarios for integrated modeling and analyses

Session organizer(s): Gokul Iyer (PNNL)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

This session comprised five talks on various approaches to developing subnational scenarios. Over the past decade, the SSPs and RCPs have been developed to facilitate climate change impact, mitigation, adaptation, and vulnerability studies across a number of research communities. The underpinning framing of the SSP-RCP framework is that climate is the main source of adverse consequence to society. However, a number of multi-sector modeling studies focused on subnational scales have begun to explore the co-evolution of human and natural systems such as energy-, water-, and land- related systems. A key conclusion of Jae Edmonds' talk, which was based on results from a workshop, was that these studies consider a broad suite of stressors including both, those are climate related and those that are not. In addition, these studies are exploring long-term stressors such as population changes, technological breakthroughs, governance and institutional changes as well as short-term stressors such as extreme weather events (e.g. droughts and heat waves). This session included presentations of research efforts to develop scenario frameworks that are conceptually broader than the SSP-RCP framework and more suitable to subnational multi-sector modeling studies.

In particular, efforts to suit the needs of subnational multi-sector studies are being undertaken by the U.S. multisector dynamics community (Iyer et al.). This community is characterized by the use of complex models and modeling frameworks spanning a wide range spatial (e.g. global to national to subnational), temporal (sub-hourly and hourly to annual to multi-decadal), and process resolutions  to conduct such analyses. Iyer et al.'s scenario framework is conceptually different from the SSP-RCP framework in two ways. First, the framework is agnostic to the source of adverse consequences to society. The framework includes climate along with other stressors. It also includes short-term and long-term stressors. Second, the framework is bottom-up addressing stress conditions that are relevant from subnational perspectives. By providing a systematic organizing principle (e.g. by providing a consistent set of assumptions about future stressors), the framework can be used to develop subnational stress scenarios with a view to developing a shared understanding at the national level. Another notable effort is to create a framework for China with subnational detail based on energy growth (low to high) and growth pattern (homogenous to heterogenous) by Yu et al.

Two other presentations focused on extending the SSP-RCP framework to study: i.) energy-water-land nexus issues in the Indus river basin (Parkinson et al.) and ii.) local climate related issues in Japan (He Chen et al.). In particular, the Japanese study by He Chen et al. developed revised storylines for the SSPs by incorporating local perspectives.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

The SSP-RCP framework provides a very good starting point for bottom-up efforts such as those by Iyer et al. and Yu et al. For example, Iyer et al. presented an application of their framework for a large-scale modeling study focused on subnational U.S. energy-, water-, land-related systems. The authors have conducted systematic interviews with researchers in the project to identify a set of key drivers and assumptions in those drivers that could result in high stress. Notably, the results of the interviews did not include international drivers. If future studies using Iyer et al's work require assumptions about international drivers, the SSPs could be used as a starting point to develop those assumptions.

In addition, although the Iyer et al. and Yu et al. frameworks do not directly use the SSP-RCP framework (for example, by employing downscaling mechanisms), they do acknowledge the need for users of their frameworks to create ex-post links to the SSP-RCP framework to facilitate comparison with studies that use that framework.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

This session demonstrated the need for subnational scenario frameworks that are more bottom-up and take into consideration, the multi-variate decision-making that subnational planners often deal with. However, given that many existing studies are already using the SSP-RCP framework as their basis to construct scenarios, it is important to develop mechanisms by which alternative bottom-up scenario frameworks can be linked to the SSP-RCP framework for easy comparability across studies. Additionally, it would be beneficial to foster collaboration between the global SSP-RCP and the subnational U.S. multisector communities to understand the relationships between various frameworks and develop mechanisms to foster sharing of knowledge and data.

*What are other key highlights from your session?*

NA

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

The frameworks that were presented in this session could be useful for subnational modeling community – in particular, for studies conducting multisector multiscale analyses using tools that span a wide range of spatial (global to national to subnational), temporal (multi-decadal to annual to sub hourly) and process resolutions.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

Iyer et al. are planning to write a series of papers discussing their conceptual framing, and applications to modeling research. They also intend to work on quantitative scenario discovery techniques. Parkinson et al. are also preparing a manuscript for publication.

## SDGs

Session title: Improving the SSPs to assess the Sustainable Development Goals

Organizers: Keywan Riahi (IIASA), Detlef van Vuuren (PBL)

### 1. Introduction

The session started with a brief introduction of the organizers, Detlef van Vuuren and Keywan Riahi. They indicated that there is an increasing interest to use scenarios to identify pathways towards meeting the SDGs. Such scenarios could play an important role to assess the solution space within a multi-objective framing. Scenarios that cover the SDGs assume a broader framing and help to contextualize climate change challenges. In this context, Sustainable development pathways could play an important role to connect climate scenarios (see, e.g., the IAMC scenario database hosted by IIASA) with the broader development agenda. SD Scenarios that are linked with the SSP framework are also ideal tools to analyze synergies and trade-offs between the possible activities required to meet different SDGs. Hence, the SSPs provide an attractive starting point: although developed originally for climate research – they also cover other aspects relevant for analyzing the future of the SDGs. Several studies, such as GEO6, TWI2050 and CD-LINKS, have started to apply the SSP framework for the assessment of SDGs. Hence, now would be a good time to look at the lessons learned from these studies, and to discuss how the SSP framework may be extended/improved to facilitate SDG related assessments.

### 2. Speakers

The first speaker, Caroline Zimm, introduced project “The World in 2050” which is aimed at developing pathways towards meeting the SDGs in 2030. Caroline Zimm in particular discussed the first report identifying 6 major transitions and summarizing existing scenario work in the context of the SDGs. She also indicated the work on developing a limited set of indicators describing the SDGs (so-called target space).

The second speaker, Barry Hughes, indicated how the IFs model can be used to model pathways in meeting the SDGs. He presented that the IFs scenarios are in particular strong in addressing the more social-goals such as those related to education and poverty.

The third speaker, Keywan Riahi, presented the work done in the CD-LINKS project. Here, several IAMs were used to analyse the possible synergies and trade-offs of scenarios meeting the Paris climate goals for the SDGs. The analysis showed that there were more synergies than trade-offs. Important synergies are, for instance, related to air pollution. Possible trade-offs relate to the use of land for bio-energy (and subsequent impacts on biodiversity or food prices). He also indicated that such trade-offs can be avoided if proper measures are taken.

The fourth speaker, Laurent Drouet, subsequently discussed scenarios aimed at meeting both climate goals and air pollution goals. He showed how the WITCH IAM can be extended to also analyse consequences for air pollution.

The next speaker, Lorenza Campagnolo, indicated how strategies to meet SDGs are impacted by climate change – by focusing particularly on the agriculture sector.

Keigo Akimoto indicated how focusing more on the question how to reduce energy demand can identify pathways to meeting multiple SDGs. Specifically, in reducing energy demand he looked at the so-called sharing economy.

Mathias Weitzel looked at the air pollution consequences of mitigation pathways – showing possible synergies, this time using JRC's POLES model.

Shonali Pachuari introduced a new topic, i.e. The question how to meet the SDG goal on energy – and more specifically how to reduce the use of solid biomass.

Finally, Heleen van Soest presented work on the linkages between various SDGs and the ability of IAM models to address these. The analysis showed first of all possible linkages between the SDGs based on expert judgement and literature analysis. In parallel, IAM modellers were asked to indicate which linkages were captured by existing IAM models and how new model development could lead to further modelling of linkages between the SDGs. The analysis identified an agenda for further development of IAM models.

3. Questions

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The session discussed how the SSP/RCP framework could potentially be used to look at meeting SDG targets. Clearly, in the SSP1 sustainability scenario it will be comparatively the easiest to meet the SDG objectives – but similar to climate goals, it might also be interesting to analyze the possibility to meet SDGs based on other SSPs. This would foster a better understanding of how different socioeconomic conditions may foster or hinder the achievement of SD. A proposal was made to create an alternative matrix in which the "radiative forcing" axis is replaced by an axis indicating the ambition in meeting the SDGs. Further progress would require a better description of the SDG dimensions in the narrative, further development of new scenarios, and finally improvements of modeling frameworks to better cover the different SDG dimensions. The presentations showed examples of how this can be done for many of the SDGs.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

The broad formulation of the SSPs makes them useful for SDG analysis. However, considerable further development is needed – in particular for issues related to distributional issues, equity, governance, and other SDGs related to social goals.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

See above.

*What are other key highlights from your session?*

See above

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

All

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

There were no explicit new activities. However, projects that bring together many actors from the community like CD-LINKS and TWI-2050 proved to be useful platforms for further activities.

## Taking Stock

Session name: Developing the SSPs: Taking Stock of Successes, Areas to Improve for the Future

Session organizer(s): Eric Kemp-Benedict (Stockholm Environment Institute), Jonathan Lamontagne (Tufts University)

*What particularly notable advances have been made in the topic area of this session that involved using or further developing the SSP-RCP or other (please specify) scenario frameworks?*

The session was a retrospective panel discussion that went beyond any single topic. But to orient the audience, each panelist said how they had used the SSPs in their own work. These included, among others: a systematic review of all global food modeling & projection studies, local climate planning in Europe, and the US National Climate Assessment (NCA). In the first project, the panelist noted that in contrast to pre-SSP scenario exercises, those that used the SSPs could be more easily compared and aggregated. In the local study, the team had developed extended SSPs, with a particular focus on upscaling. The NCA required agencies to use both the SSPs and the RCPs. Despite the use of the common framework, they faced some

challenges in aligning state-level and federal scenarios because certain topics (such as wildfires) were particularly relevant to that state, but not to all states.

In response to a later prompt, one panelist noted that he had heard of high-quality research at the Forum. For him, putting question of socioeconomic conditions in the future at the forefront of research is good outcome. It takes us from asking simply, “How will things go?” to, “How will they coevolve?” In a related comment, another panelist noted that the SSPs reintroduce the idea of governance into the climate debates; not just climate governance, but other forms as well, including the role of political institutions that are not led primarily by climate concerns.

*What features of the SSP-RCP or other scenario frameworks helped or hindered progress in the topic area of this session?*

Panelists noted that it is helpful to say, “We’re going to use scenarios developed for IPCC”. It carried weight in the policy world. The RCP/SSP framework also helps to integrate mitigation and adaptation. Granted, the weight is different than that for the SRES scenarios, which were “stamped” by IPCC rather than being designed by the “global research community” to support the IPCC and others. Neither approach had an obvious advantage.

As in the previous comment, the consistent framework helped to incorporate global impact modeling studies into local studies. At the local level, these can be modified with a “building blocks” approach; where quantifications don’t fit, the scenario team can proceed with stakeholder-led inputs. Framing these along the two axes forces stakeholders to think of mitigation and adaptation together. Despite the local modifications, the common framework made it possible to compare scenarios between different local teams.

The SSPs managed to engage IAV much more than in SRES. Maybe not as much as hoped, but definitely yes. They provided a common language that sparked more dialogue and exchange. (Although sometimes the language was not a good fit.) Moreover, using the SSPs forces other research communities to adopt a longer time scale than they are used to. E.g., for agriculture, the normal horizon is maximally 2050 [EKB: that is, about 30-35 years depending on when the study was done]. But that doesn’t cover even one generation! This is very positive, but it does raise problems about how those research communities can engage with that time horizon.

The SSPs also facilitated cross-scale studies. Before the SSPs ever emerged, there was demand for understanding multi-scale interactions, socioeconomic scenarios, and meeting needs of IAV community. The SSPs provided a coherent way to manage the madness, helping to corral and maybe accelerate some of that effort. Once they were created, the SSPs precipitated new work.

*What key modifications, additions to, or extensions of the scenario framework would be most helpful for future work in the topic area of this session, and what research gaps would they address?*

The matrix architecture provides great flexibility, but it is sometimes confusing for stakeholder audiences. We need to think about how to encourage people to go beyond SSP2. And one participant, on first exposure to framework, thought it was “bonkers”, particularly around communication: Why separate SSPs & RCPs? In their workshops, experienced, high-level global change researchers don’t understand the parallel process. This panelist acknowledged that the framework and associated parallel process seems to work to a degree, but was not a good fit to the participant’s work.

This led to a question: The RCPs & SSPs are used extensively in water resources but they don’t know where they come from. What’s the responsibility for the research community on how they’re used? If it’s for the community, it would be nice if everyone in the community understands what’s going on. But do they need to know what’s going on? Do you need to know the team, the model, etc. to use GDP or population time trends?

The axis labels were helpful for climate scenarios, but not otherwise (e.g., they were not a good match for IPBES). So, uptake beyond climate studies may be limited. It was particularly difficult to link to development issues. What is needed is a range of development pathways. In principle, SSP 4 & 5 should help with this, but it was not what they were designed for.

More broadly, the SSPs to a large degree reflect Western (North American & Western Europe) viewpoints. All of the authors were based in those regions [EKB: although the panelist noted that I was located in Thailand at the time.] First, we need some feedback on applying the SSPs in a developing country context. Beyond that, there is a need to broaden the perspective both by bringing in additional contributors and by doing cross-checks with current and historical examples: e.g., the panelist argued that the Communist Party of China doesn’t really fit in any SSP.

Another panelist noted that the scenarios do not adequately stress citizens as agents of change. The SSPs are welcome, but a next step is needed exploring dynamics of conflict, tensions, and convergence that happen in real social settings. It was suggested that activists, and not just researchers and decision-makers, be included in future forums. The specific example given is the “alternative food movement”. The panelist did a study with them, and while not an advocate, noted that the movement’s vision cannot be fit into any of the SSPs.

There is a need for materials to help connect the global narratives and the RCPs to local realities. For example, linking loss of permafrost to Inuit suicide. Having the extremes (e.g., RCP 8.5) was helpful for exploring tail risks, but uptake was just about zero. A lot more communications work is needed to translate down to local (in this case, county) scale for decision-makers and researchers.

The drivers [EKB: I think this means the quantitative drivers from the IIASA database] aren’t what appear in the SSP narratives. Also, while the different population scenarios are within a reasonable range, the GDP scenario vary widely between modeling teams.

On specific SSPs:

- SSP4 didn't fit in existing archetypal scenario schemes, so something novel is nice! But it is also harder to understand and extend.
- Nothing in the SSP framework maps well onto the "regional sustainability" archetype of IPBES: need [at least?] two versions of SSP1 to compare and contrast.

*What are other key highlights from your session?*

On the local scale, the scenario development process is crucial. Stakeholder buy-in is needed, not just local detail. That gets challenging. E.g., from a US perspective, states are local, but from California perspective a city or county (e.g., Los Angeles) is local. How do we deal with myriad of questions across all levels of governance, where they have to make decisions today that will lock things in for the future? (And how to take the local scenario development up to planning processes at larger scales?)

*What audiences (researchers, practitioners, policymakers) do you think would most benefit from the scenario-related work in the topic area of this session?*

This panel session provided feedback from practitioners/users to ICONICS and the broader community about future development of the climate scenarios.

*What plans for follow-up activities (meetings, publications, projects, etc.) related to the topic area of this session are you aware of?*

None are planned, but at least one panelist said a serious study is needed, beyond a single panel discussion. What have we learned? And how to move forward?

Beyond that, there were suggestions for what to do in the future (it was a focus of the panel):

- Allow for additional SSPs: If the framework isn't working for you then make a new one. Waiting for the framework to come to you isn't the way to go.
- Extended SSPs are being developed, on both geographic and sectoral lines. (But mostly geographic.) It could be beneficial if the framework provided guidelines on how extensions should be developed. It may be time to review what's been done and come up with recipes/guidelines.
- Suggestion for developing a scenario framework: Survey existing scenarios, then build narratives rather than the other way around. [EKB: This was the approach taken by the Global Scenario Group, which constructed "archetypes" based on a review of future visions.]
- Use techniques from Futures Studies/Foresight, e.g.:
    - Morphological fields with different drivers and states. [EKB: This is quite compatible with CIB, which is isomorphic to a morphological field.] Morphological analysis be used with multiple stakeholders, and there is a range of tools and techniques to choose from.

    - Expanded scenario set to allow study of desirable futures. There is a worry that the SSPs will introduce a problematic standardization that hinders research on alternative futures.
    - To really push people and clarify thinking, allow for “impossible” combinations of drivers at certain points in scenario development.
- Spend time identifying and quantifying new indicators (e.g., for the food sector).
- Add defense & security: Like environmental studies, using sophisticated scenario methodologies. But the communities don’t talk and are naïve about each other’s issues.
- Expand the notion of “technology”: Not just IT/digitization. Biotechnology, nanotechnology. And considering worlds in 2100, it seems implausible not to stress role of AI in that future. What about future of work? Totally central. AI + synthetic biology and nanotechnology a totally different vision of the future.
- In certain policy worlds, have to go for 1.5 target because it’s the Paris agreement: but frequently told, “We’re never going to get there.” So: Know we have to get to zero emissions eventually. How do we get there as fast as possible? We need national decarbonization studies that deal with political economy, jobs, etc.

## Tracking progress

Session name: Scenarios for Tracking Progress in International Climate Policy

Session organizer(s): Joeri Rogelj, IIASA/Imperial College London

This session set out to provide a platform to explore and present how scenarios can contribute to informing the new international policy architecture that was adopted as part of the 2015 UN Paris Agreement. This architecture of five-yearly stocktake cycles consists of country-level climate action pledges (referred to as Nationally Determined Contributions or NDCs), which are regularly assessed and updated with the aim of limiting warming to well below 2°C or 1.5°C relative to preindustrial levels. Science is given a key role in the assessment of these pledges and their adequacy in achieving the Paris Agreement’s long-term temperature goal.

After an introductory presentation about scenarios that describe the current state of play of NDCs, four presentations provided four very distinct perspective of the topic. The first of these presentations covered the importance of emissions reductions and climate action over the next decade for limiting warming to 1.5°C – the most stringent target included in the Paris Agreement Long-Term Temperature Goal (LTTG). It highlighted that if emissions reductions are delayed until 2030, this would imply socio-technical transitions until mid-century consistent with limiting warming to 1.5°C that might be infeasible. Stringent policies in energy-demand sectors, particularly in industry and transportation, would be required in addition of supply-side reduction to trigger an immediate peak of global emissions. A second presentation took a broader perspective to climate targets and potential impact by focussing on the implications of NDCs for sea-level rise. It showed that it is possible to track the sea level rise commitment of present day emissions, but that extending the analysis of impacts of current emissions to 2300 is necessary for a more meaningful assessment of future sea level rise impacts. By 2300, the sea level rise commitment implied by the emissions of current NDCs would exceed 1m. The third oral

contribution provided an anthropologic retrospection of the evolution and changes in the four scenario sets used by IPCC. It provided preliminary insights based on literature research and interviews. While elucidating the past role of scenarios in policymaking, it concluded that to be policy relevant, scenarios always need to have specific objectives, which relate to the policy questions of the times. Finally, the last contribution presented preliminary results of the implications of global coal power developing for delivering the Paris Agreement, which show how attaining the Paris Agreement LTTG requires accelerated retirement of existing power capacity.

These presentations, as well as the panel discussion that followed, also allowed to identify a set of key lessons for scenario design and use for tracking the achievement of the Paris Agreement. The SSP framework has been applied in several of the studies presented during the session and was generally seen as a good basis for studies supporting tracking the achievement of the Paris Agreement. However, also a set of key barriers in the current scenario framework approach were identified that hindered the usefulness of scenarios for their use in tracking progress in the UNFCCC. A mismatch between time-horizons was identified, which could be bridged by combining near-term scenarios with detailed time steps for next two decades, and linking them to long-term transitions, not only over the next century but at least until 2300. This would be required to clarify the implications of near-term decisions for longer term and at times irreversible impacts. Furthermore, it was also highlighted that climate policy processes were more focussed on peak warming than on the precise warming in the year 2100. Currently, however, the SSP/RCP scenario matrix approach frustrates the assessment of both policies that allow to keep peak warming to a specific level, and of assessments of impacts and consequences of longer timescales. There also seems to be a timing mismatch between scenario creation or design and their use in climate policy. International climate policy under the UNFCCC has a clear timeline to which scenarios should cater. Unless this is explicitly taken into account, valuable scenario information might not be in a position to fulfil its role in informing policy. Finally, the session also highlighted the importance of further engagement on policy and political processes in a scenario-based way, exploring both what is still possible and what is not.

### Transition dynamics

Session name: Socio-technical transition dynamics in scenarios for climate change mitigation and sustainable development: where next?

Session organizers: Evelina Trutnevyte (University of Geneva), Nico Bauer (Potsdam Institute for Climate Impact Research), Detlef van Vuuren (Utrecht University)

Speakers and panel discussants: Oreane Edelenbosch (Politechnico di Milano), Simona Pedde (Wageningen University), James Glynn (University College Cork), Aleh Cherp (Central European University), Roberto Schaffer (COPPE), Adam Hawkes (Imperial College London)

Background: The question whether long-term targets can be reached depends on a range of factors, including technical, economic, social and environmental considerations. Different disciplines study these questions, including model-based scenario analysis and research on

social-technical transitions. While the former has proven to be an effective tool to link long-term targets and short-term action, most models focus predominantly on economic and technical factors. In order to understand the feasibility of future transitions, scenarios need to better account for social, cultural and political factors that are covered in socio-technical transition analysis. This session asked: what is the state of the art and what are the research needs for developing representations of socio-technical transitions in future scenarios in order to better capture the structural transformations for climate change and sustainability analysis?

Notable advances for using or further developing the SSP-RCP and other scenarios: There was a clear consensus in the session that further work is needed in order to better represent socio-technical transition dynamics in scenario analysis, including the SSP-RCP frameworks. In particular, there are two interlinked elements that are important determinants of the future emissions or energy outcomes and that are potential levers for change, but that also get rarely represented in exiting scenario frameworks and/or models:

- Socio-technical interplay: behavior and lifestyles, governance, societal capacity to transform, decision-making rationales and preferences of the key actors (beyond consumers), interests and conflicts, myopia, material and non-material needs, policy diffusion etc.
- Transition dynamics: Pathways to reaching the climate/energy goals, transition speed, pathway dependencies, feedback loops, social dynamics, social tipping points, transition barriers that are inherent in socio-technical conditions, etc.

The presentations in the session showed various experimentations that are ongoing in this field, ranging from quantitative modeling to qualitative social science theories and participatory science-society interactions. Yet, there is still a lot of integrative research that needs to be done in order to find coherent, generalizable, quantifiable and transferable insights that can feed into SSP-RCP and similar scenario frameworks and/or models.

Features of the SSP-RCP framework that help or hinder progress: We agreed that there is room for improvement to better integrate socio-technical transitions in the SSP-RCP framework. Even if most of the work so far concentrated on technical and economic factors, these factors need to better link with the underlying social and political dynamics and future challenges. This is an important observation because, when used for policy support, SSP-based scenarios may underplay the role of social and political elements in future emissions and energy outcomes as well as may overlook the potential levers of change.

Modifications, additions, or extensions of the scenario framework needed: The SSP-RCP scenario framework and/or related models shall clarify what considerations of socio-technical transition dynamics are part of the scenarios/models already and then improve on the representation of the missing elements. In parallel, preparatory work is needed in order to identify the coherent, generalizable and transferable evidence on which elements can be realistically included and how.

Key highlights of the session: The session's speakers and panel discussants brought complementary perspectives to the topic of socio-technical transition dynamics and this eventually led to an extensive "to do" list for future research:

1. Identify and transparently document what assumptions on socio-technical transition dynamics are already in SSP-RCP applications, other scenarios and/or models.
2. From the missing elements, identify those that can have the highest impact on future emissions and energy outcomes and that can serve as realistic levers for change.
3. Conduct integrative research in order to find coherent, generalizable, quantifiable and transferable ways on how the relevant elements of socio-technical transition dynamics could be further represented in the SSP-RCP applications and other scenario frameworks and/or models. This can be achieved by integrating elements dynamically in models, or by integrating knowledge into qualitative model elements (e.g.narratives).
4. Investigate questions on data availability as well as on the endogenous vs. exogenous model representations of socio-technical transition dynamics.
5. Experiment with modifications and extensions of existing integrated assessment and other models in order to test the architecture and limits of these models and to understand what can be modelled endogenously, e.g. derive stylized facts or operationalize the modeling of social capital or governance.
6. Ensure that the modeling is not only done at a level of an individual or a consumer, but reaches out to big-picture socio-technical trends and all types of actors.
7. Experiment with new modeling frameworks, e.g. agent-based models and try to integrate that with integrated assessment models of climate change.
8. Be open to a diverse range of disciplinary communities as well as qualitative and quantitative methods, e.g. narratives vs. models, that are relevant for representing socio-technical transition dynamics in scenario frameworks and/or models.
9. Ensure that scenario frameworks and/or model outputs meet the needs of the intended users by engaging in co-design and even participatory processes with citizens.

Audience that most benefits from the work: The improvement of representation of socio-technical transition dynamics would benefit all types of audiences: researchers themselves, practitioners, policy makers, and even citizens. The potential audience is tightly linked with spatial scales and contextual situations at hand, where different elements of socio-technical transition dynamics have stronger weights.

Follow-up activities (meetings, publications, projects, etc.) related to the topic area: A perspective article is planned; various research projects are ongoing, among others EU Horizon 2020 project NAVIGATE (2019-2023) and PARIS REINFORCE (2019 – 2021).

## Urban

Session title: Urban futures under the new scenario framework

Organizers: Guillaume Rohat (University of Geneva), Felix Creutzig (Mercator Research Institute)

Introduction
The session on “Urban Futures under the New Scenarios Framework” was made of five different oral presentations, which covered aspects related to (1) the spatially explicit quantification of urban land expansion under the different SSPs at the global scale, (2) the role that SSPs play in shaping future cooling gaps and heat-related vulnerable populations in urban areas of the Global South, (3) the contribution of population growth and urbanization – under certain SSPs – to future exposure to deadly heat in large cities, (4) the contribution of population growth and spatial urban development patterns to future exposure to dangerous heat in cities worldwide, and (5) innovations and electrification in U.S. cities under different types of urban futures, using a typology-based approach.

Particularly notable advances made in the topic of urban futures, using the SSP-RCP Framework:
So far, the SSP-RCP framework enabled exploring future urbanization patterns under different types of socioeconomic development and future heat-related challenges in urban areas, under different levels of climate change and different types of socioeconomic development. The scenario matrix proved to be a useful tool to explore the contribution of socioeconomic development to future heat-related health challenges, as well as its contribution to reducing climate risks in urban areas. The SSP-RCP framework enabled to shed light on the important role that socioeconomic and urban development play in shaping future climate risk outcomes (in the case of this session, heat stress risk) in urban areas. The SSPs, employed alone, also enabled to explore the influence of different types of socioeconomic development and policies (as implied by the narratives) on future urbanization patterns and urban land use Expansion.

Features of the SSP-RCP framework that helped exploring urban futures or that hindered progress:
The qualitative aspects of the global SSPs (narratives and table of trends) were useful to quantify future urbanization patterns and urban land use expansion at the global scale, as they contain a few assumptions about urbanization level and type for each SSP. However, most of the work presented in this session did not rely on the qualitative aspects of the SSPs, but rather on the quantitative projections at the national scale, in particular population, urbanization, and GDP projections.

The lack of qualitative description in the SSPs about city-scale processes (e.g. urban planning and urban governance) hindered the use of the SSPs narratives for urban studies, and the lack of city-level projections hindered the use of the SSPs quantification at the city scale.

Modifications, additions, and extensions of the scenario framework that would be helpful for future work:
Extension of the SSPs’ narratives for urban-related topics would be very helpful in order to apply SSPs in urban areas. Qualitative information about urban morphologies, spatial development, urban governance, slums development, urban inequalities, mobility, digitization, electrification of mobility, etc. would undoubtedly help better characterizing

urban futures under the different SSPs. Similarly, quantitative information at the city-level (e.g. population counts, demographic characteristics of urban dwellers, etc.) would help applying the SSPs in quantitative IAV studies at the urban scale.

Key highlights

The key highlights of this session relate to the acknowledgment that (1) applications of the SSP-RCP framework (or other scenarios-based frameworks) have to be mainstreamed in climate risks assessments at the urban scale, (2) there is a lack of interest in the influence of SSPs on urban emissions, and (3) the impact of the SSPs on urban climate outcomes is an interesting and relevant research topic for the coming years.

(1) Because cities are places where most people and assets are concentrated and because these are highly dynamic areas (particularly in developing country), applications of the SSP-RCP framework to explore urban futures is critical. It was agreed in the session that there is a need to increase the use of the SSP-RCP framework at the city-scale. There has been too few applications so far. Nevertheless, a number of questions were also raised about the suitability of the global SSP-RCP framework for city-level and intra city-level IAV studies. Bottom-up approaches with locally developed scenarios might be more appropriate at such local scale. This feeling was reinforced by the existing “behavioral” differences between the national trends and the trends at the city level (e.g. for economic development, ageing, population growth, etc.).

(2) Another key highlight of this session was the lack of existing work on the influence of SSPs on urban emissions. Most of the audience appeared to be from the IAV community, with little to no interest in the mitigation/emission side of the SSPs. Since cities account for more than two thirds of global carbon emissions and consume over 60% of the world’s energy, it still appears crucial to explore future city-level carbon emissions under the different SSPs.

(3) The audience showed a large interest in the influence that different types of urban development would have on the urban (micro)climate. Because three presentations focused on heat stress, the issue of accounting for the urban heat island (UHI) under the different SSPs was raised at several occasions, and was considered an interesting and highly relevant research topic in the coming years.

Audiences that would benefit from the scenario-related work in this topic

Because of the local scale at which urban processes take place, local policy-makers (e.g. mayor’s office) as well as local practitioners (e.g. urban planners) appear to be the ones who would most benefit from scenario-related work in urban areas. This is particularly the case if the credibility and buy-in of the scenarios is ensured. Nevertheless, policy-makers working at the global scale – in institutions such as UN-Habitat – would also benefit from multi-city comparison studies (which was the case for three presentations in this session). Challenging research questions (e.g. projecting multi-cites UHI under different SSPs) might also be of high interest to researchers in urban studies and the climate research community.

Plans for follow-up activities:

Considering the lack of urban-related information in the SSPs’ narratives and the lack of quantification at the urban scale, the need for developing extended urban SSPs for IAV studies

in cities was raised, although no concrete follow-up activities were discussed.