7th ANNUAL MEETING

Society for Decision Making under Deep Uncertainty

5-7 November 2019

Delft, The Netherlands

Securing Sustainable Futures

Designing, planning, and making decisions on policies, practices, and infrastructures under deep uncertainty

Welcome to Delft City, The Netherlands!

On behalf of the organizing committee for the 2019 meeting of the Society for Decision Making under Deep Uncertainty. Welcome to Delft, The Netherlands. Nowadays, Delft is a small college town with a large expat community due to the university, the European Pattent Office in the neighboring town of Rijswijk, and the various international organizations in the Hague. Historically, however, Delft was a major trading town and this history is still very visible in the historic city center.

Four years ago, the third deep uncertainty workshop also took place in Delft. It was hosted by Deltares and organized in close collaboration with TU Delft. It was the first workshop outside of the United States. This year, we return to Delft but now at TU Delft and again organized in close cooperation with Deltares.

This year's theme is securing sustainable futures. Globally all kinds of initiatives are being deployed to improve the world. Whether it is about improving access to education, eradicating poverty, or mitigating climate change, it turns out that making a difference is not easy. In moving from ambitions and objectives to action we have to confront various deep uncertainties. The approaches being developed, tested, and applied in practice by the various members of our society can be of substantial help in this. Looking at this year's program, it is good to see that the analytical core is well represented, while simultaneously links to related fields, topics, and application domains are actively being pursued.

This year's workshop would not have been possible without the funding provided by the Delft Deltas, Infrastructures & Mobility Initiative and the Faculty of Technology, Policy and Management both at Delft University of Technology, the Dutch Delta Programme, and Deltares.

Jan Kwakkel

2019 Organizing Committee

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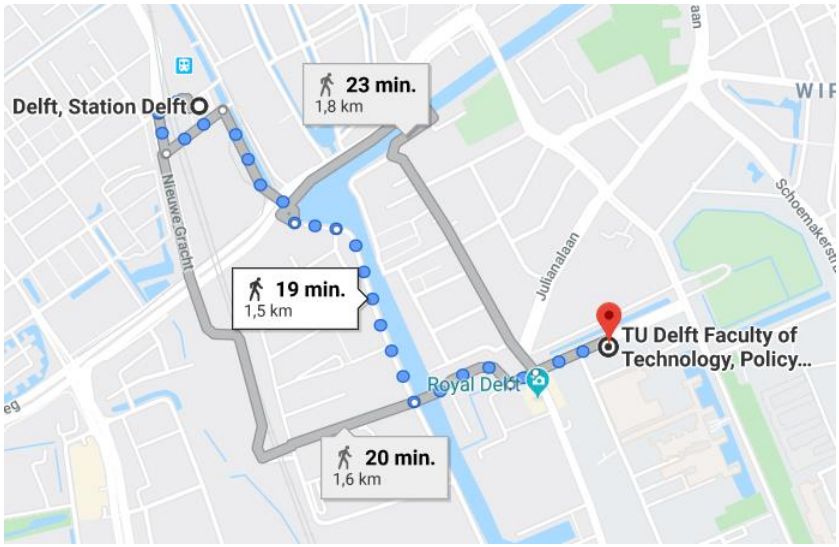
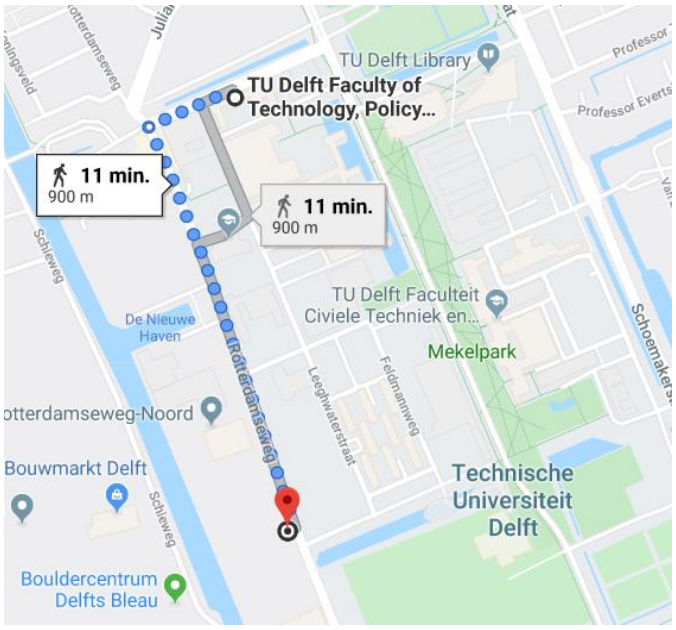
Training, Meeting, and Dinner Venues



The venue for the training day and the annual meeting is at **TU Delft, Faculty of Technology, Policy, and Management (Jaffalaan 5, Delft)**. This is within a walking distance from the Delft Central Station. Several bus routes are also available from this station to the venue (Bus 40, 55, 69, 174 (take stop 'TU Aula')).



On Wednesday, November 6th we will have dinner at **Lijm & Cultuur (Rotterdamseweg 270, Delft)**, which is also within a walking distance from the main venue. We will leave together from the Faculty (main entry) at around 17:45.

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DMDU 2019 Annual Meeting Agenda

Agenda: Training Day

Tuesday, 5 November 2019

TU Delft (Faculty of TPM), Jaffalaan 5, Delft

08:30 – 09:00	**Registration**
09:00 – 09:30	**Introduction to the Training Day (Room H-I-J)**
09:30 – 11:00	**Interactive exercise: The varieties of uncertainty (Room H-I-J)**
11:00 – 11:30	**Coffee break**
11:30 – 12:30	**Generalized framework for DMDU methods: A guide to the field (Room H-I-J)**
12:30 – 13:00	**Overview of parallel demos (Room H-I-J)**
13:00 – 14:00	**Lunch**
14:00 – 14:45	**Demo Session 1** - Rhodium (Room G) - EMA Workbench (Room H) - RDM Tableau Tools (Room I) - DAPP, Pathways generator, and Sustainable Delta Game (Room J) - Argentina Transport Risk Analysis (ATRA) Tool (Board Room)
14:45 – 15:15	**Coffee break**
15:15 – 16:00	**Demo Session 2 (same options as Demos 1 with SAlib added in room SimLab)**
16:00 – 17:00	**Practitioners panel and Q&A: DMDU in application (Room A)**

Agenda: Day 1

Wednesday, 6 November 2019
TU Delft (Faculty of TPM), Jaffalaan 5, Delft

08:30 – 09:00	**Coffee & Registration**

09:00 – 10:30	**Opening Plenary (Room A)**
	- Opening & icebreaking session
	- Keynote speeches:
	  o Karen Meijer: Water-related conflicts and migration – the importance of understanding human responses to water shortage
	  o Tatiana Filatova: Resilience and decision-making under deep uncertainty: building bridges
	  o Casey Helgeson: Where are the values in your analysis?
	  o Nidhi Kalra: Can Congress Contemplate Deep Uncertainty?

10:30 – 11:00	**Coffee**
11:00 – 12:30	**Parallel session - Supporting decision making under deep uncertainty with participatory approaches (Room A)** Chair: Vincent de Gooyert, Willem Auping, Etiënne Rouwette Co-designing multiple futures in a participatory approach applied to Texel, the Netherlands Floortje d'Hont, Jill Slinger Formulating an adaptive plan to implement innovative concepts with experts' opinion, an application to Mobility-as-a-Service Peraphan Jittrapirom, Vincent Marchau, Rob van der Heijden, Henk Meurs, Enhancing Urban Mobility through a Participatory DMDU "Shadow" Planning Process Tim McDonald, Thomas Small, Robert Lempert, Steven Popper, Diogo Prosdocimi Using participatory scenario development for modelling forest landscapes as social-ecological systems (SESs) Melvin Lippe, Anastasia Yang, Richard Fischer, Sven Günter **Parallel session - Developing robust defense and security strategies and plans (Room G)** Chair: James Maltby, Sean Monaghan

	WEI-WUV for Assessing Force Effectiveness: Managing Uncertainty with Info-Gap Theory Yakov Ben-Haim Evaluating Enterprise Level Acquisition Timelines Under Deep Uncertainty Sarah Moody, Stephanie Martin, Matthew Walsh, Brian Carter Introducing civilian population into wargaming: experimental study of NATO Civil-Military Cooperation. Natalia Wojtowicz Helping the US Army Assess Surge Expansion with RDM Steven Popper **Parallel session - Techniques to support long-term strategic decision making under deep uncertainty for energy and other infrastructures (Room I-J)** Chair: Will Usher, Elco Koks, Raghav Pant Supporting the biofuel debate with stochastic modelling of greenhouse gas emissions Judith Verstegen, Renan Barroso, Floor van der Hilst The Uncertainty and Sensitivity of Long-Term Urban Water Demand Forecasts: how wrong can you be? Alexa Bruce, Casey Brown, Alexis Dufour Robust design of off-grid hybrid energy systems under climatic and technological uncertainty Federico Giudici, Andrea Castelletti, Elisabetta Garofalo, Holger R. Maier Using artificial neural networks for long term adaptive decision making in water systems. James Tomlinson, Julien Harou
12:30 – 14:00	**Lunch (Room F) + Posters (Room H)**
14:00 – 15:30	**Parallel session - Decision making under uncertain sea level rise: A special DMDU case? (Room A)** Chair: Marjolijn Haasnoot, David Behar, Judy Lawrence, Natasha Barlow, Goneri Le Cozannet, Tim Reeder, Detlef Stammer Deep uncertainty in the KNMI'2021 sea level projections Dewi Le Bars, Sybren Drijfhout. Robert Vos

Matching observed records of local sea level rise to long term projections for flexible adaptation planning
Bart van den Hurk, Sybren Drijfhout, Fedor Baart, Dewi le Bars, Renske de Winter, Marjolijn Haasnoot

Practical appraisal of extra-probabilistic approach to support decision-making under deep uncertainty for future coastal flooding
Jeremy Rohmer, Goneri Le Cozannet. Jean-Charles Manceau

Impact of regional sea-level rise on European sandy coasts under high-end scenarios
Remi Thieblemont, Gonéri Le Cozannet, Alexandra Toimil, Íñigo J. Losada, Benoit Meyssignac, Melisa Menendez

Coastal decision-making under deep-uncertainty or near-certainty? — the New Zealand case
Scott Stephens, Judy Lawrence, Rob Bell

Robust and flexible land reclamation strategies in the Maldives
Jochen Hinkel, Thomas van der Pol

Parallel session - Combining network science and deep uncertainty methods to inform transport resilience planning (Room I-J)
Chair: Julie Rozenberg, Raghav Pant

Road show: comparing road network resilience in 210 countries
Julie Rozenberg, Charles Fox, Mersedeh Tariverdi, Elco Koks, Stephane Hallegatte

River flood disruptions of the European road network: a tipping point for Europe?
Kees C.H. van Ginkel, Elco Koks, Lorenzo Alfieri, Francesco Dottori, Luc Feyen

Equity considerations in transport network criticality analysis
Bramka Arga Jafino, Jan Kwakkel

Using network science to improve the resilience of transportation networks under seismic hazard
Nazli Yonca Aydin

	Transportation and Supply Chain Resilience in the United Republic of Tanzania Celian Colon, Hallegatte Stéphane, Julie Rozenberg Ensuring a Resilient Road Network in the Western Balkans with Deeply Uncertain Natural Hazards Kelly Klima, Craig Bond, Miriam Marlier, Robert Lempert, Monika Crouse, Peter Bar, Jennie Topham, Michael Green Transport risk and resilience analysis under uncertainty Raghav Pant, Elco Koks, Tom Russell, Jim Hall **Parallel session - Moving towards adaptive governance for sustainability under conditions of complexity and deep uncertainty (Room G)** Chairs & presenters: Zora Kovacic, Silvio Funtowicz, Roger Strand, Dominique Chu 1. Silvio Funtowicz: "Uncertainty" 2. Dominique Chu: "Complexity" 3. Zora Kovacic: "Sustainability" 4. Roger Strand: "Crisis" 5. Plenary debate open to the audience 6. Final conclusions by panel
15:30 – 16:00	**Coffee**
16:00 – 17:30	**Parallel session - Decision making under uncertain sea level rise: A special DMDU case? (Room A)** Chair: Marjolijn Haasnoot, David Behar, Judy Lawrence, Natasha Barlow, Goneri Le Cozannet, Tim Reeder, Detlef Stammer Exploring the effects of adaptation strategies on population migration under uncertain sea-level rise Lena Reimann, Bryan Jones, Claudia Wolff, Athanasios Vafeidis Test of introducing a policy pathway approach to sea level rise in municipal planning in Sweden Riitta Raty, Annika Carlsson Kanyama, Christoffer Carstens, Karin Mossberg Sonnek, Per Wikman-Svahn UK contribution to Decision making under uncertain sea level rise: a special DMDU case Tim Reeder, Jason Lowe, Natasha Barlow, Ivan Haigh

	Sea level rise scenarios used in the United States David Behar Reflecting on highly uncertain sea level rise and the use of DMDU approaches: experiences from the Netherlands Marjolijn Haasnoot, Ferdinand Diermanse, Jaap Kwadijk, Bart van den Hurk, Dewi Le Bars, Jos van Alphen **Parallel session - Innovations for scenario discovery when seeking dynamic, robust, and resilient action pathways (Room I-J)** Chair: Patrick Reed, Jan Kwakkel, Jon Lamontagne Behavior-based scenario discovery Patrick Steinmann, Willem Auping, Jan Kwakkel Premortem and DMDU: separated by a common purpose James Maltby, Gareth Conway, Jim Maltby Increasing adaptation in urban planning. An adaptation pathways approach to mitigate the hydrological risk in the X Municipality of Rome Simona Mannucci, Jan Kwakkel, Hedwig Van Delden A Scenario Discovery Approach for Designing Dynamic, Robust Adaptive Strategies: Optimization and Machine Learning Algorithms for Estimating Critical Thresholds and Adaptation Options Edmundo Molina, David Groves, Steven Popper **Parallel session - A decision capability framework: Matching decision capabilities to decision support approaches to make more effective decisions in deep uncertainty (Room G)** Chair: Katy Roelich, Mark Workman and Muriel Bonjean Stanton From root to crown: Exploring the fit between capabilities and robust decision support approaches at different decision levels in forest management Roderich von Detten, Naomi Radke Logistics Decision Capabilities and Support Approach Towards Effective Decision in Nigerian Health System: A Study of Tertiary Health Facilities. Francis Andem
17:45	**Group departing from meeting venue to dinner restaurant**
18:00 – 21:00	**Dinner**

Agenda: Day 2

Thursday, 7 November 2019

TU Delft (Faculty of TPM), Jaffalaan 5, Delft

08:45 – 09:00	**Coffee**
09:00 – 10:30	**Parallel session - The use of data and information for decision making in humanitarian crises (Room I-J)** Chair: Tina Comes 1. Juriaan Lahr (Information needs in different challenges) 2. Marc van den Homberg (Several case studies) 3. Kashif Nadeem Muhammad (Mozambique case) 4. Freek Huthoff (Mozambique case) 5. Stuart Campo (Information needs in different challenges) 6. Olga Aymerich (Iraq case) 7. Philippe Ker Rault (Iraq case) **Parallel session - Innovations for scenario discovery when seeking dynamic, robust, and resilient action pathways (Room A)** Chair: Patrick Reed, Jan Kwakkel, Jon Lamontagne Defining robustness, vulnerabilities, and consequential scenarios for diverse stakeholder interests within the Upper Colorado River Basin Antonia Hadjimichael, Julianne Quinn, Erin Wilson, Patrick Reed, Leon Basdekas, David Yates, Michelle Garrison Consequential Compromises: Exploring the Cooperative Stability of Multi-Actor Robustness Compromises in Regional Infrastructure Investment Pathways David Gold, Bernardo Trindad, Patrick Reed, Gregory Characklis Coordination and control: Limits in standard simulation-based vulnerability assessments of complex multi-reservoir systems Charles Rougé, Patrick M. Reed, Danielle Grogan, Shan Zuidema, Alexander Prusevich, Stanley Glidden, Jonathan Lamontagne, Richard B. Lammers Using the scenario discovery approach to identify winners and losers of adaptation policies under uncertainties Bramka Arga Jafino, Jan Kwakkel

	Parallel session - Institutions and governance arrangements: Enabling forward-looking decisions under uncertainty by governments (Room G) Chair: Wieke Pot, Art Dewulf, Judy Lawrence Protecting and representing the interests of future generations in policy making Samuel Hilton Balancing equity and efficiency in adaptation to climate change: Decision-making on resource allocation at the city scale Hanne van den Berg Assessing the adaptive capacity of peri-urban institutions as part of an adaptive pathways approach for water management in India Sharlene L. Gomes, Leon M. Hermans Bridging Two Approaches for Sustainable Development: Decision Making under Deep Uncertainty (DMDU) and Transition Management (TM) Shirin Malekpour, Warren Walker, Fjalar de Haan, Vincent Marchau, Niki Frantzeskaki Uncertainty and credibility, Experience in supporting a local institution in Benin aimed at dealing with (deep) uncertainty. George de Gooijer, Maman Daouda
10:30 – 11:00	**Coffee**
11:00 – 12:30	**Parallel session - Practical challenges in the application of DMDU methodologies to climate risk assessment and management (Room A)** Chair: Ad Jeuken, Umit Taner, Casey Brown, Patrick Ray Mainstreaming DMDU approaches into water resources practices - The DTF experience Diego J. Rodriguez, Homero A. Paltan, Luis E. Garcia A streamlined approach to applying DMDU methods for climate-resilient infrastructure planning - Lessons from Mendoza, Argentina Michelle Miro, David Groves, James Syme, Alejandro Becerra, Guillermo Cúneo, Juan Andrés Piña, Adrien Vogt-Schlib, Valentina Saavedra Gomez

Communicating climate change risk for an investment project in irrigation and flood protection in West Kenya
Marnix van der Vat, Luis Garcia, Johannes Hunink, Homero Paltan, Diego Rodriguez, Dana Stuparu

Parallel session - Incorporating values in modelling and decision analyses (Room I-J)
Chair: Casey Helgeson, Nancy Tuana

A method selection framework for developing pathways to sustainability under uncertainty
Enayat A. Moallemi, Brett A. Bryan, Shirin Malekpour, Katrina Szetey, Michalis Hadjikakou, Angela M. Rojas, Abdullah Shaikh, Fjalar J. De Haan, Alex Smajgl, Emily Nicholson, Euan G. Ritchie, Alexy Voinov, Wikke Novalia

Operationalizing ethical principles in flood risk management: A case study on the Dutch-German Rhine
Alessio Ciullo, Jan Kwakkel, Karin de Bruijn, Neelke Doorn, Frans Klijn

Climate policy considering heterogenous world views
Sara Turner, Lisa Rennels, Robert Lempert, David Anthoff

Trust and values at the science-policy interface
Marina Baldissera Pacchetti

Parallel session - Finding the tipping point - Deep uncertainty for resilience engineering in coupled & complex systems (Room G)
Chair: Tina Comes, Tatiana Filatova

Lifelines: the resilient infrastructure opportunity
Stephane Hallegatte, Jun Rentschler, Julie Rozenberg

The uncertainty space in urban planning
Supriya Krishnan, Tina Comes

Using surrogate models to analyse resilience of ABMs
Guus ten Broeke, George Van Voorn

Operationalizing Urban Resilience: A Machine Learning Approach
Mikhail Sirenko, Scott Cunningham, Yilin Huang, Alexander Verbraeck

12:30 – 13:30 **Lunch (Room F) + Posters (Room H)**

13:30 – 15:00 **Parallel session - Practical challenges in the application of DMDU methodologies to climate risk assessment and management (Room A)**
Chair: Ad Jeuken, Umit Taner, Casey Brown, Patrick Ray

A systematic exploration of change in the Tuolumne River Watershed
John Kucharski, Wyatt Arnold, Saiful Haque Rahat, Jennifer Olszewski, Romain Maendly

Robust decision making for sustainable development: Classifying, sequencing, and evaluating alternative methodological choices
Enayat A. Moallemi, Fateme Zare, Patrick M. Reed, Sondoss Elsawah, Michael Ryan, Brett A. Bryan

Selection of the smallest subset of informative scenarios for the robust optimization of off-grid hybrid energy systems
Federico Giudici, Matteo Giuliani, Andrea Castelletti, Holger R. Maier

From risk assessment to adaptation pathways: improvement of Climate Risk Informed Decision Analysis for the Limari basin in Chile
Chris Luger, Ad Jeuken, Koen Verbist, Andrew Warren, Christopher Vivanco, Hector Maureira, Pablo Álvarez

Parallel session - Fostering connections between resilience thinking and DMDU approaches for achieving long-term sustainability (Room I-J)
Chair: Benjamin Bryant, Jan Kuiper

Embracing theoretical and methodological pluralism in resilience thinking and DMDU
Wei Liu

Building bridges: Lessons from resilience planning and applied RDM analysis in Pittsburgh, Pennsylvania
Jordan Fischbach

Resilience as an analytical uncertainty
Patrick Steinmann, George van Voorn

Uncertainty and multifunctionality as bridging concepts from socio-ecological resilience to infrastructure finance in water resource decision making
Anita Lazurko (remote)

	Toward Supply chain resilience: consequence-based risk analysis using exploratory modeling Bahareh Zohoori, Jan Kwakkel, Alexander Verbraeck
15:00 – 15:30	**Coffee**
15:30 – 16:30	**Parallel session - Embracing uncertainty in regional energy planning and management (Room I-J)** Chair: Cornelia Colijn, Mark Alan Hughes, Oscar Serpell Extending Shared Socioeconomic Pathways: Developing multi-scale internally consistent scenarios for Canada's energy futures Jude Herijadi Kurniawan, Vanessa Schweizer Participatory multi-modelling under deep uncertainty for robust energy infrastructure development strategy Igor Nikolic, Jan Kwakkel, Eefje Cuppen, Jaco Quist Using DMDU Methods to Evaluate the Robustness of Costa Rica's National Decarbonization Plan David Groves, Edmundo Molina, Luis Fernando Victor Gallardo, Guido Godinez Zamora, Jairo Quiros Tortos, Felipe De Leon, Valentina Saavedra Gómez, Adrien Vogt-Schilb **Parallel session - Ex-post evaluation of deep uncertainty in infrastructure design (Room G)** Chair: Marc Neumann Do we understand performance dependencies, trade-offs, information value, and robustness in dam design and operation? Federica Bertoni, Andrea Castelletti, Matteo Giuliani, Patrick M Reed Quantifying the feedbacks between flood infrastructure and geomorphological processes in an uncertain deltaic environment: A case study of the coastal zone of Bangladesh Amelia Paszkowski, Jim Hall How high to elevate a house to manage deeply uncertain flood risks? Mahkameh Zarekarizi, Klaus Keller **Parallel session - The deep uncertainties of legislative processes (Room A)** Chair: Nidhi Kalra, Steven Popper, Robert Lempert

	Can Congress Contemplate Deep Uncertainty? Nidhi Kalra The Road to Zero: DMDU Concepts in Support of Legislative Coalition Building Steven Popper Can Credible Commitment to Long-Term Policy Goals Be Accomplished? Detlef Sprinz
16:30 – 17:30	**Closing Plenary (Room A)** - Keynote speech: Paul Davis - Closing remarks from the DMDU Society's Board
17:30 – 18:30	**Closing Reception**

Abstracts: Training Day Demos

Rhodium

Rhodium is an open source Python library for robust decision making (RDM), many-objective robust decision making (MORDM), and exploratory modeling. These decision-support frameworks enable the identification of robust strategies for the management of complex environmental systems, by evaluating the tradeoffs among candidate strategies, and characterizing their vulnerabilities. Rhodium facilitates rapid application of the RDM and MORDM frameworks by providing a suite of optimization, visualization, scenario discovery, and sensitivity analysis functions. Rhodium is written in Python and can interface with models written in Python, C and C++, Fortran, R, and Excel. The source code is freely available at https://github.com/Project-Platypus/Rhodium.

EMA Workbench

There is a growing interest in model-based decision support under deep uncertainty, reflected in a variety of approaches being put forward in the literature. A key idea shared among these is the use of models for exploratory rather than predictive purposes. Exploratory modeling aims at exploring the implications for decision making of the various presently irresolvable uncertainties. This is achieved by conducting series of computational experiments that cover how the various uncertainties might resolve. Exploratory Modeling and Analysis (EMA) is a research methodology that uses computational experiments to analyze complex and uncertain systems (Bankes, 1993). That is, exploratory modeling aims at offering computational decision support for decision making under deep uncertainty and Robust decision making. The EMA workbench aims at providing support for performing exploratory modeling with models developed in various modelling packages and environments. Currently, the workbench offers connectors to Vensim, Netlogo, and Excel, although it has also been used with other simulation packages such as Anylogic, Simio, Arena, etc. The EMA Workbench is implemented in Python. It is designed to (i) support the generation and execution of series of computational experiments; and (ii) support the visualization and analysis of the results from the computational experiments. The EMA Workbench enables users to easily perform exploratory modeling with existing models, identify the policy-relevant uncertainties, assess the efficacy of policy options, and iteratively improve candidate strategies. The EMA workbench also has support for parallel processing on both a single machine as well as on clusters.

RDM Tableau Tools

Rapidly deployable decision support tools help facilitate deliberation with analysis—a key aspect of RDM applications and for other DMDU approaches as well. They support deeper understanding by enabling analysts and stakeholders to explore results of hundreds to millions of simulations. They enable robustness analyses to be dynamic and respond to different stakeholder expectations or values. Lastly, they can support actual decisionmaking by being relevant, timely, and easily deployed and usable. There are a variety of different software packages that can be used to develop such decision support tools. The more useful are data agnostic, flexible, easy to use and deploy, and affordable. This demo will describe how Tableau Software has been used across several different RDM research projects, each focusing on a different aspect of decision support. Examples include long-term water resources planning in Monterrey, Mexico; post hurricane disaster planning in Puerto Rico; and flood risk assessment and mitigation prioritization in the San Francisco Bay Delta.

DAPP, Pathways generator, and Sustainable Delta Game

Dynamic Adaptive Policy Pathways (DAPP) is a DMDU approach that explicitly includes decision-making over time. The essence is proactive and dynamic planning in response to how the future actually unfolds. It explores alternative sequences of decisions or actions (development or adaptation pathways) under multiple futures, and illuminates the path-dependency of options. These actions have uncertain design lives, and may fail sooner or later to achieve their

objectives as the conditions change (i.e. they reach an adaptation tipping point), or may not be feasibly implemented until certain conditions exist (i.e. they reach an opportunity tipping point). Different pathways achieve the specified objectives under changing conditions, with these typically visualized in a Metro-map or decision tree against a time or condition axis. DAPP supports planners in designing a dynamic adaptive plan that covers short-term actions, long-term options, and adaptation signals to identify when to implement actions or revisit decisions. During the demo, we briefly introduce the DAPP approach and reflect upon its application both in the Netherlands and internationally over the past 7 years. In the demonstration, we highlight some recent advances and lessons learned from these applications, including: the validity of the approach to diverse policy problems, contexts, and resources; the development of methodologies to economically evaluate pathways; the design of effective signalling systems to monitor pathway performance; and the development of a software application to generate pathways maps.

Argentina Transport Risk Analysis (ATRA) Tool

ATRA (Argentina Transport Risk Analysis) Tool: This tool has been developed for the Government of Argentina to undertake transport vulnerability assessment for designing, building and maintaining climate change resilient infrastructure. Transport criticalities and risks are measured in terms of increases in the transport costs and widespread macroeconomic losses resulting from loss of access when key linkages fail. By quantifying the costs and benefits of climate resilience options for each network link, we can identify locations for prioritizing investments into climate adaptation. Such large-scale analyses add several layers of uncertainties accounted for by adopting a simulation-based approach of testing for network link failures. This is done by (1) simulating extreme floods driven over multiple climate models; (2) quantifying uncertainties in transport network costs, freight flows and economic loss outcomes; (3) analysis of different flood intersections with transport assets and simulating failure outcomes of all network nodes and links; (4) accounting for different ranges of adaptation investments sensitive to the flood exposures; (5) quantifying the benefits of avoided losses and accessing their sensitivity to different disruption durations and GDP growth forecasts; and (6) performing a cost-benefit analysis to identify network links for climate resilience planning.

The underlying model has been developed in Python programming language and provided to the GoA as an open-source tool: https://github.com/oi-analytics/argentina-transport. The web-based tool presented in this training workshop is a results inquirer, meant for the stakeholders to be able to understand and interpret the model results and inform their climate resilience investment policies in Argentina.

SAlib

SALib is an open source library written in Python for performing sensitivity analysis. SALib provides a decoupled workflow, meaning it does not directly interface with the mathematical or computational model. Instead, SALib is responsible for generating the model inputs, using one of the sample functions, and computing the sensitivity indices from the model outputs, using one of the analyze functions. A typical sensitivity analysis using SALib follows four steps:

1. Determine the model inputs (parameters) and their sample range.
2. Run the sample function to generate the model inputs.
3. Evaluate the model using the generated inputs, saving the model outputs.
4. Run the analyze function on the outputs to compute the sensitivity indices.

SALib provides several sensitivity analysis methods, such as Sobol, Morris, and FAST. There are many factors that determine which method is appropriate for a specific application, which we will discuss later. However, for now, just remember that regardless of which method you choose, you need to use only two functions: sample and analyze. To demonstrate the use of SALib, we will walk you through a simple example.

Abstracts: Day 1
Wednesday, 6 November 2019

Supporting decision making under deep uncertainty with participatory approaches (Room A)

Chair: Vincent de Gooyert, Willem Auping, Etiënne Rouwette

Co-designing multiple futures in a participatory approach applied to Texel, the Netherlands

Floortje d'Hont, Jill Slinger

In this paper, we report an innovative co-design process that explores multiple uncertain futures with community stakeholders, authorities and disciplinary experts. This co-design process was tailor-made to fit the local, highly dynamic context of the South Western part of Texel, the Netherlands, and included three interlocking participatory workshops.

In the first workshop, local stakeholders co-designed utopian and dystopian futures, drawing on scientific and local knowledge and perspectives. In a second workshop, professionals with specialized disciplinary expertise relating to coastal management, engineering, and research were informed of the stakeholder values distilled from the first workshop, before they co-designed feasible solutions. Their designs used nature-based solutions, and identified implementation challenges located in the policy and institutional domains. In the third workshop, local experts validated the previous co-design outcomes. The eventual output can be regarded as the product of a network of engineers, local stakeholders, authorities and scientists from social and natural disciplinary backgrounds.

Although the current trend in coastal management and planning is to embrace participation for long-term decision-making, community stakeholders are rarely invited to join at the idea generation phase. With this participatory approach, we demonstrate that co-designing from the outset enriches the solution space for interventions in the natural, institutional and social subsystems. Local knowledge is found to be critical in crafting policy to fit the site-specific and dynamic nature of the coast and her communities.

Formulating an adaptive plan to implement innovative concepts with experts opinion, an application to Mobility-as-a-Service

Peraphan Jittrapirom, Vincent Marchau, Rob van der Heijden, Henk Meurs

Mobility-as-a-Service (MaaS) is an innovative transport concept that integrated different modes of transport and offered them to travellers through a single platform on their smartphones. MaaS is expected to provide travellers with a highly convenient door-to-door mobility service, which also improves the sustainability and operational efficiency of the transport system. However, the lack of real-life operations and related experience on MaaS instigate several uncertainties surrounding the concepts. For example, it is uncertain how different transport operators will collaborate to operate MaaS or whether MaaS will eventually result in positive societal impacts. These uncertainties can limit its wider and successful implementation. In this study, we combine the Dynamic Adaptive Policymaking (DAP) framework with the Delphi method to formulate an adaptive plan to cope with these uncertainties. Previously, DAP is formulated through a desk-top study or within a small group of experts. Our approach improves the DAP by involved a panel of international experts through the Delphi Method, a structured group communication technique. The approach enhances the level of comprehensiveness and broadens the perspectives included in the plan in comparison to a typical DAP process, making the plan more implementation-ready. In this paper, we describe the process and report the enhancements of the DAP-Delphi approach. Additionally, we discuss possible improvements to the process and how this novel approach can be applied to support the planning of other innovative concepts, such as AI and Smart city.

Enhancing Urban Mobility through a Participatory DMDU "Shadow" Planning Process

Tim McDonald, Thomas Small, Robert Lempert, Steven Popper, Diogo Prosdocimi

In 2017 the Los Angeles municipality of Culver City released a plan for re-imagining the future mobility in the city's downtown district, reducing reliance on cars by reshaping the urban landscape and creating alternative modes for moving to, from, and through the city. Implementing the plan presented Culver City with a significant challenge. Their vision represented transformational change, requiring significant shifts in the city's landscape and the expectations and habits of its citizens at a time of rapid and often bewildering expansion of tech-enabled mobility options.

To help address this planning challenge Culver City partnered with RAND to develop an implementation plan for the city. This partnership focused on two key concepts: decision making under deep uncertainty (DMDU), and a "shadow" process of citizen involvement providing space for exploration and experimentation in parallel to and interacting with the city's formal planning. The process was also designed to ensure diverse voices of those affected could be heard in a manner that will both enhance the accurate targeting of the ensuing plans and widen the circle of consensus.

This talk describes this DMDU shadow process, its impacts, and strengths and weaknesses. RAND conducted a series of scenario visioning and stress-testing workshops with residents, city staff, and developers. These workshops, and supporting analysis, generated a phased implementation plan that informed and accelerated the city's formal process, which is now being implemented. This approach may also help other cities grappling with the mobility challenges of our tumultuous times.

Using participatory scenario development for modelling forest landscapes as social-ecological systems (SESs)
Melvin Lippe, Anastasia Yang. Richard Fischer, Sven Günter

Dynamic and spatially-explicit scenario modelling supports policy making in understanding the complex adaptive nature of social-ecological systems (SESs) such as forest landscapes. We require better understanding of what people want and need from the natural environment and the impacts these have on it, and how policies navigate trade-offs and synergies in such systems. In complex SESs (where certainty is low, data availability is limited, and management of resources is ongoing and adaptive), using participatory procedures for including a wide array of stakeholders during the scenario modelling process is central to effectiveness and value. This can strongly impact scenario results and policy design. In many cases however participation remains tagged on haphazardly during the scenario development process, or merely pays false lip service to. These omissions have the potential of fatally undermining the value of such kind of SESs modelling. Especially in a world that is increasingly being connected and multi-scale, solutions must be as well.

Using the case of the Philippines, we present the first outcomes of a series of participatory procedures (focus group discussions, key informant interviews, participatory mapping) to elucidate stakeholders narratives, ranking scores and relevant information for scenario modelling of forest landscape. Participatory procedures were conducted at local, regional, and national scale incorporating a wide array of relevant institutions and actors. Our findings highlight the contrasting viewpoints of government agencies, landscape managers and people at the different administrative scales, demonstrating the need for using stakeholder-driven scenarios in landscape modelling for designing policies that are target-specific and context-sensitive.

Developing robust defense and security strategies and plans (Room G)

Chair: James Maltby, Sean Monaghan

WEI-WUV for Assessing Force Effectiveness: Managing Uncertainty with Info-Gap Theory
Yakov Ben-Haim

The WEI-WUV algorithm (Weapon Effectiveness Index-Weighted Unit Value) purports to assess the effectiveness of a system of weapon systems based on a linear function of the quantities of each weapon type. The WEI-WUV algorithm has been widely criticized and indeed fallen into disrepute. The foremost limitations are (1) the need for subjective choice of numerical coefficients to represent complex and subtle situations, and (2) the linearity of the WEI/WUV function not accounting for synergy or competition between force elements. Is WEI-WUV really passé, out of date, of little or no use? In this paper we employ info-gap decision theory to model and manage the very real uncertainties that accompany a WEI-WUV assessment. We demonstrate how the impact of parameter and functional uncertainties can be assessed, and how the WEI-WUV algorithm can be used in supporting responsible decision making. We also explore the value of additional information when confronting dispute among experts about the values of WEI-WUV parameters. Numerical examples of land force effectiveness are presented, showing the trade-

off between effectiveness and robustness against uncertainty. We also show that the analysis of robustness can lead to a reversal of preference between the putatively better but more uncertain option, and the more conventional but less uncertain option.

Evaluating Enterprise Level Acquisition Timelines Under Deep Uncertainty
Sarah Moody, Stephanie Martin, Matthew Walsh, Brian Carter

Systems within the space enterprise such as imaging and communication satellites are developed in a deeply uncertain environment where unexpected system failures and schedule delays may result in the loss of critical services and data products. Past studies exploring acquisition strategies for a space enterprise have considered the uncertainties with either the health of the systems within the enterprise or the timing of the acquisition of future system, but not both in conjunction. The health of the current space systems dictates the likelihood that the enterprise will be able to satisfy user needs, and therefore has significant impact on the future acquisition schedule. This study presents a framework that accounts for both sources of uncertainty and explores different acquisition strategies of space systems that have robust performance at the space enterprise level. We adopt the Many-Objective Robust Decision Making (MORDM) framework to the space enterprise acquisition problem and leverage the Genetic Resources for Innovation and Problem Solving (GRIPS) tool, an Aerospace suite of multi-objective optimization algorithms, to explore the trade-space of space enterprise acquisition options. This framework is applied to an exemplar space enterprise designed to support humanitarian relief efforts from natural disasters around the world. We explore the resulting solution space comprised of acquisition options with tradeoffs between cost, acquisition portfolio size, and robustness to uncertainties in acquisition and system life.

Introducing civilian population into wargaming: experimental study of NATO Civil-Military Cooperation.
Natalia Wojtowicz

Basic model of the wargaming process in military features two opposing sides - friendly (blue) and enemy (red). This research extends the player catalogue and makes adjustments to mechanics to replicate the presence of civilian population in conflict. The experimental study provides a method of comparative analysis between wargames which include population and those that follow the basic model.

Helping the US Army Assess Surge Expansion with RDM
Steven Popper

The U.S. Army had traditionally been a small force-in-being, designed to surge in size during times of war, as during WWII, and then draw down. Since the Korean and Vietnam wars, its size had varied but has not needed to confront the question of surge in response to major international challenges for at least three decades, if not longer. It has been forced far more frequently to consider how to cut best rather than to surge. Much of the institutional knowledge and direct experience with expansion has been lost from the service. In fact, the National Commission on the Future of the Army, charged by Congress in 2014 to assess and make recommendations regarding Army force structure, made serious attention to the issue of expansion one among its 62 recommendations.

This session will report a Robust Decision Making analysis designed not only as a tool for supporting thinking on expansion but as an illustration introducing to the Army a completely new approach to such planning based on DMDU concepts and methods. The simple analysis was designed to illustrate a search for alternative postures that would provide a robust stance toward surge, balancing being able to meet various potential future requirements for recruitment, training, equipping and sustaining large forces with minimizing costs that might prove to be unsustainable or politically inviable in the absence of a present threat. This study was sufficient to cause the Army to request more substantial analytical and support effort along these lines based on DMDU principles.

Techniques to support long-term strategic decision making under deep uncertainty for energy and other infrastructures (Room I-J)

Chair: Will Usher, Elco Koks, Raghav Pant

Supporting the biofuel debate with stochastic modelling of greenhouse gas emissions
Judith Verstegen, Renan Barroso, Floor van der Hilst

The sustainability of biofuels has been criticized over the past decades, as the cultivation of its feedstock may trigger greenhouse gas (GHG) emissions from land use change (LUC). Yet, the order of magnitude of the projected GHG emissions has differed widely across various modelling

exercises. Some scholars have therefore argued that GHG emissions from LUC are "too uncertain" to be incorporated in legal sustainability standards for biofuels.

In our opinion, it is more constructive to turn the argument around: What is the likelihood that the average projected GHG emissions of biofuel production are below a desired threshold, given the uncertainty in the models? We show how stochastic, spatially-explicit models of land use change and carbon emissions in combination with statistical methods, i.e. Monte Carlo analysis and exceedance probabilities, can be applied to answer this question. This is demonstrated for a study of bioethanol production in Brazil, under a Business-As-Usual scenario and five scenarios with potential LUC-emission mitigation measures. As the desired threshold we use the GHG-emission saving threshold for biofuels defined by the revised Renewable Energy Directive (REDII).

Out of the preliminary GHG emission projections of our six scenarios, none are found to be certainly above the threshold, four straddle the threshold, and two are certainly below the threshold. The two well-performing mitigation measures are 1) using eucalyptus instead of sugar cane as feedstock, and 2) shifting towards second generation bioethanol from highly-productive sugar cane in combination with strict forest conservation measures.

The Uncertainty and Sensitivity of Long-Term Urban Water Demand Forecasts: how wrong can you be?
Alexa Bruce, Casey Brown, Alexis Dufour

Forecasting water demand is highly uncertain, influenced by macro level socioeconomic and climatic factors, as well local behaviour of consumers. Pervasive approaches to estimating demand are largely deterministic in nature with little to no attention paid to the envelope of uncertainty within which they sit. Studies that do account for uncertainty do so in a deterministic fashion – typically by defining 'high' and 'low' scenarios. Much progress has been made in establishing approaches to characterise the uncertainty associated with the impact of climate change on water supply. Such approaches have demonstrated their utility in facilitating robust decisions under deep uncertainty. We argue here that water demand constitutes an additional dimension of 'deep' uncertainty. We apply well established methods from DMDU scholarship to explore the sensitivity of a regression model of demand for the San Francisco Bay Area. We apply quasi-random sampling to independent variables to develop many thousands of plausible realisations of future demand from 2010-2070. We use the results of this analysis to explore the sensitivity of the model to each of the independent variables through linear regression and global sensitivity analysis. Finally, we employ Principle Component Analysis and the Patient Rule Induction Method to understand which conditions lead to 'unacceptably' high values of demand. We find the range of uncertainty associated with the demand model in question to be significantly larger than previous studies and establish income growth and the uncertainty associated with correlation coefficients of income and price elasticity to be the primary determinants of this uncertainty.

Robust design of off-grid hybrid energy systems under climatic and technological uncertainty
Federico Giudici, Andrea Castelletti, Elisabetta Garofalo, Holger R. Maier

Small islands are remote off-grid systems where energy security is generally based on carbon intensive diesel generators, which are usually oversized to meet peaking summer energy demand driven by high touristic fluxes. Due to the lack of accessible water sources, potable water is produced by energy intensive desalination technologies, which strongly impact on the energy system, increasing air pollution and greenhouse gas emissions.

To improve the sustainability of these systems, recently a transition from fossil fuel to clean-energy technologies has been taking place. The high renewable potential of the islands is exploited through hybrid energy systems, which combine traditional power production (e.g., diesel) with renewable energy sources (e.g., PV, wind) and storage technologies. In the future, the performance of these systems will be strongly affected by deep uncertainty in climatic conditions and technological innovation. This uncertainty will pose a challenge in the identification of the best system design able to guarantee high levels of sustainability over a medium-long term horizon.

In this work we first generate a large set of future scenarios considering uncertainty in both climatic drivers (e.g., solar radiation, wind speed) and technological variables (e.g., efficiency and costs of power generation) and then we assess the robustness of different hybrid system designs with respect to these scenarios using multiple robustness metrics.

Expected results allow to identify the key drivers that more significantly influence the system performance in terms of

different sustainability indicators, and explore the dependency of the best system design upon the choice of the robustness metric.

Using artificial neural networks for long term adaptive decision making in water systems.
James Tomlinson, Julien Harou

Several methods have been proposed to incorporate adaptive planning into long term capacity expansion planning of water systems. In addition the use of robust optimisation to accommodate deeply uncertainty futures has also become popular. Adaptive planning methods typically require the definition of indicator metrics and the discovery of thresholds, via optimisation, to trigger specific actions. It is a challenge for planners to identify effective indicator metrics. For example, water planners could consider metrics related to streamflow, climate, weather, population, or consumption. In addition the types of statistical summary (e.g. rolling average window length) for each indicator are also varied and difficult to identify. When combined with a large number of feasible actions the number of indicator-threshold-action combinations can become intractable. The planner must reduce this number to make a computationally feasible optimisation formulation, and thereby is required to make a priori assumptions regarding which indicators are most effective.

In this work we seek to apply artificial neural networks (ANN) to the adaptive planning problem where the knowledge of which indicator is most effective is not known a-priori. The ANN is trained using a multi-objective evolutionary algorithm (MOEA). Each period in our simulation model the indicator values are input to the ANN to determine which actions, defined by the strength of output neurons, to take in the following period. We investigate whether the use of this ANN can improve upon existing approaches, and allow the planner to accommodate more indicators without prior knowledge.

Decision Making Under Uncertain Sea Level Rise: A Special DMDU Case? (Room A)

Chair: Marjolijn Haasnoot, David Behar, Judy Lawrence, Natasha Barlow, Goneri Le Cozannet, Tim Reeder, Detlef Stammer

Deep uncertainty in the KNMI'2021 sea level projections
Dewi Le Bars, Sybren Drijfhout. Robert Vos

Climate scenarios generally treat socio-economical uncertainties, like greenhouse gases emissions, as deep uncertainty while quantifying uncertainties arising from the natural systems. In particular, this is the case of sea level scenarios developed globally by the IPCC and locally by institutes like KNMI and UKMO. However, two recent developments make this clear separation less and less justified. First, the need for high-end scenarios by flood risk managers and policy makers is pushing scientists to focus on the high tail of the probability distributions, above the 95th percentile, precisely where the projections are highly sensitive to weakly constrained assumptions. Second, it has recently become clear that physical processes driving ice sheet mass loss are badly understood but potentially have an enormous impact on sea level rise at century time scale.

Here we present a method to define a range of possible sea level projections that will provide a deep uncertainty envelop to the future KNMI'2021 probabilistic sea level scenarios. We make use of extra-probabilistic tools recently applied to sea level projections. On the one hand, this information opens new possibilities for co-production of scenarios with the users and for a better communication of the meaning of the uncertainties in sea level scenarios. On the other hand it raises new questions like: when can peer review science be used for adaptation decisions? Can uncertain science help decision making? These questions will be discussed in the presentation.

Matching observed records of local sea level rise to long term projections for flexible adaptation planning
Bart van den Hurk, Sybren Drijfhout, Fedor Baart, Dewi le Bars, Renske de Winter, Marjolijn Haasnoot

For near-term planning of shoreline maintenance by beach nourishment observed trends are used to give an indication of expected near-future sea level rise (SLR). For long-term adaptation strategies to cope with SLR, scenarios are used that are based on (downscaled) model projections of oceanic mass distribution and transport, and expert judgment to probe probabilities of uncertain SLR contributions from ice masses and glaciers.

Consistency between observations and scenarios is challenged by the fact that potential drivers of SLR vary over time, and may not yet contribute significantly to the present-day records while playing a major role in future scenarios (e.g. large mass loss from ice sheets). In addition, some processes that govern variability in the observed

records are not included in scenarios owing to the absence of predictable drivers (e.g. wind driven surge levels). A procedure for a seamless match between local observations to SLR scenarios is desirable. It allows construction of a narrative of the gradual evolution of SLR from the current situation to a future where SLR rates may be very different from today's. It also helps designing monitoring strategies to assess likely SLR pathways in the near- and far-future.

In this paper we describe the experience and procedures followed to match local SLR observations to future scenarios in the Netherlands. Attention is paid to the different application domains with different planning horizons, differences in physical processes in the observation and scenario products, driver-specific probability assessments, and the role of communication and science-policy interaction regarding this topic.

Practical appraisal of extra-probabilistic approach to support decision-making under deep uncertainty for future coastal flooding
Jeremy Rohmer, Goneri Le Cozannet. Jean-Charles Manceau

Decision-making in the area of coastal adaptation is facing a major challenge due to the ambiguity in the selection of a unique probability model (deep uncertainty) to represent the lack of knowledge in future sea level rise (SLR). A handful of methods exist to address this problem, but many lack practical recommendations to bring them to an operative state. Our work aims to fulfil this requirement by providing practical recommendations to support decision making under deep uncertainty using the possibility theory, i.e. an extra-probabilistic approach that avoids selecting one unique probability model (CDF) by bounding all the plausible ones consistent with the available data. The framework is applied at a local low-lying coastal French urban area on the Mediterranean coast to assess the uncertainties on the flooding probability by 2100, i.e. SLR uncertainties, the choice in Representative Concentration Pathway scenario, the ranking of high-end scenarios, the regional bias, the vertical ground motion, the contributions of extremes and waves. Our results highlight where the current knowledge prevents the assignment of a unique CDF to future flooding risks. We provide different and complementary information from the probabilistic and possibilistic viewpoints by informing the decision-maker with a single "effective" CDF, which both reflects the impact of ambiguity and his/her attitudes toward risk. If a large ambiguity exists, we ultimately propose to support the setting of learning scenarios by applying the scenario discovery process to search across the set of all plausible probabilistic models with respect to an acceptable flooding probability and of ambiguity.

Impact of regional sea-level rise on European sandy coasts under high-end scenarios
Remi Thieblemont, Gonéri Le Cozannet, Alexandra Toimil, Íñigo J. Losada, Benoit Meyssignac, Melisa Menendez

Sea-level rise is a major concern for coastal hazards such as flooding and erosion in the decades to come. Over the recent years, high-end sea-level scenarios (HESs) have informed stakeholders with low-uncertainty tolerance. However, beyond sea-level rise, projections of future hazards are crucial for coastal adaptation decision-making, raising the need for a consistent approach across all steps leading to high-end coastal hazards assessments. Here, we provide high-end projections of the contribution of regional sea-level changes to sandy shoreline retreats for Europe by the end of the 21st century. This is achieved by coupling the EUROSION coastline database with three increasingly pessimistic HESs and the conservative Bruun rule. We designed HESs based on the upper limit of the RCP8.5 scenario "likely-range" (as defined in the IPCC AR5) and on high-end estimates of the different component of sea-level projections provided in recent literature. For the three HESs, sea-level rise is projected to be higher than 1 m by 2100 for most European coasts. This translates into an average pan-European coastline retreat of 100 m for our moderate HESs, and into more than 200 m in most coasts of Europe for the uppermost HESs, except for the north of the Baltic Sea where the post-glacial rebound should damp shoreline impacts. We also show that uncertainty in the contribution of the Antarctica ice-sheet melting strongly affects the spatial distribution of European shoreline retreat. Finally, the magnitude of our shoreline retreat estimates is discussed in light of the degree of erodibility of the coast.

Coastal decision-making under deep-uncertainty or near-certainty? — the New Zealand case
Scott Stephens, Judy Lawrence, Rob Bell

There is much focus on high-end sea-level rise (SLR), but many locations globally will be impacted by small SLR in the near-term. High-end SLR scenarios are most relevant where high extreme sea levels are experienced (Cuxhaven, Germany) and/or at locations already highly engineered against these extremes (Netherlands). Conversely, New Zealand (NZ) with its smaller storm-surge regime (relative to

the tide), will experience impacts in the near decades from modest SLR with near certainty of timing and magnitude. Evidence is presented for this imminent risk along with mapping of NZ's exposure, showing rapid acceleration in the rate of exposure for SLR at levels much less than 1 m that tails off for higher SLR of up to 3 m—the urgent focus for NZ.

For high-end SLR scenarios we show how decisions for long-lived development can be monitored and triggered, then discuss how decisions at low–intermediate SLR for existing development can be made. Banking and insurance sectors are concerned with the short–medium term (present to 2050), where uncertainties and constraints for near-term decision-making are socio-economic, not physical. For example, the focus in New Zealand is on; issues of law and policy that need to be fit-for-purpose for changing risk; lack of a nationally-coordinated adaptation plan for SLR that can operate alongside devolved subnational decision making (now proposed); how communities can change and adapt to ongoing SLR and more frequent flooding; how "business-as-usual" infill development can be managed before long-term planning is implemented. We will conclude with questions for discussion.

Robust and flexible land reclamation strategies in the Maldives
Jochen Hinkel, Thomas van der Pol

The Maldives has reclaimed a substantial amount of land from the sea and the number of land reclamation projects will continue to grow to facilitate population growth and economic development, and also adaptation to rising sea levels. This paper aims to identify land reclamation strategies that avoid lock-ins (i.e. are flexible) and whose flood risk performance is robust under deeply uncertain sea-level rise. The following methods are applied to three sites: (i) a flood hazard-based design height, (ii) a scenario-based cost-benefit analysis (CBA) with follow-up actions but without new information, and (iii) a decision tree analysis (DTA) accounting for the value of new SLR information. The results show that thinking about flood hazard development alone is not enough to prevent costly lock-ins in the long run: once land is reclaimed at a given height, development is locked into a vicious cycle of adding flood protection measures if flood risk becomes too high. This, in turn, increases the risk of catastrophic consequences in the case of failure of protection measures. Actions can be undertaken to postpone such "reclaim & protect" lock-ins or mitigate their costs. The CBA shows to what extent such decisions reduce investment costs of measures to protect and costs of increased flood vulnerability, which can outweigh the additional costs of a more robust island height today. DTA is used to illustrate how low regret options may help to reduce costs of a "reclaim & protect" lock-in by accounting for the value of new SLR information.

Combining Network Science And Deep Uncertainty Methods To Inform Transport Resilience Planning (Room I-J)

Chair: Julie Rozenberg, Raghav Pant

Road show: comparing road network resilience in 210 countries
Julie Rozenberg, Charles Fox, Mersedeh Tariverdi, Elco Koks, Stephane Hallegatte

We extract Open Street Map primary, secondary and tertiary roads for 210 countries and clean each network to obtain a simplified connected graph per country. In each country we create an origin-destination matrix with 100 points, representative of the 50 most populated and 50 largest admin 1 districts in each country. We then assess the resilience of each network by calculating the network loss of functionality associated with a given loss of assets. To do so, we systematically remove network links (10,000 times per network) and compute the resulting increase in travel time, travel distance, number of isolated trips and loss of road user surplus. We propose different measures of resilience based on the descriptive statistics of functionality loss across all simulations. We also compute static network metrics of connectivity and accessibility and expose the correlations between these metrics and our measures of resilience. Our results show that some connectivity measures can be a good proxy for network resilience (in general, networks with lower redundancy are less resilient.). However, all these aggregate metrics hide the extreme scenarios that appear when a small number of critical roads are disrupted simultaneously. It is therefore necessary to always consider a large sample of functionality loss scenarios when planning for network resilience. While these extreme scenarios do not necessarily justify capital investments, they can be the basis of contingency plans.

River flood disruptions of the European road network: a tipping point for Europe?
Kees C.H. van Ginkel, Elco Koks, Lorenzo Alfieri, Francesco Dottori, Luc Feyen

River flooding is among the most profound climate hazards in Europe and poses a threat to its road transport infrastructure. Traditional continental-scale flood risk studies fail to accurately capture these disruptions because they are typically grid based, whereas roads are relatively narrow line elements which are therefore omitted. Moreover, these grid-approaches disregard the network properties of roads, which are a major source of indirect effects.

This study introduces an object-based, continental scale flood risk assessment of the European road network for the present and future climate. Direct damages are estimated using a new vector-based model: OSdaMage, which utilizes OpenStreetMap and its metadata using parallel processing techniques. We develop a new set of road-specific flood damage functions, which are validated using an observed event. These functions are surrounded by deep uncertainty, because of uncertain local flow conditions, varieties in European road designs as well as insufficient damage reporting by road operators. This uncertainty in direct damage estimates is extensively explored and compared to the climate model and climate scenario uncertainty surrounding the river discharge simulations.

Having obtained a pan-European dataset of potential road disruptions, the question arises how this data can be used to study indirect network effects. We showcase preliminary results of a vulnerability analysis of reduced connectivity of European NUTS-2/3 regions and associated economic impacts. We compare a qualitative approach (identifying vulnerable regions and exploring their economic structure and critical industries) with a quantitative approach using regional accessibility and connectivity metrics.

Equity considerations in transport network criticality analysis
Bramka Arga Jafino, Jan Kwakkel

Transport network criticality analyses aim at identifying critical hotspots in a transport network. Results from such analyses are often used to identify promising transport infrastructure investments. Most criticality analysis studies take a utilitarian stance, where the criticality of transport network components is assessed based on their contribution to the aggregate performance of the transport system. Accordingly, they disregard the existing service inequalities experienced by transport users. This may be problematic as it has been argued that decisions taken on the basis of analyses that are grounded in utilitarian moral principles exacerbate existing inequalities.

To account for inequalities in criticality analysis, we systematically incorporate key concepts from the transport equity literature into criticality analysis. This entails explicitly defining the unit and the subject of the distribution, and operationalizing distributive principles commonly found in transport studies. We use the Bangladesh freight transport network as a case study. First, we classify transport users (subject of distribution) based on their origin and destination districts. The criticality of a link will later be evaluated based on its contribution to the potential accessibility (unit of distribution) experienced by the users. Second, we generate weighted OD matrices, where the weighing is based on four alternative principles: proportionality, equality, equalization, and minimum standard. Third, we assign the trips to the transport network to identify criticality links for each OD matrix. Lastly, we observe how the criticality patterns change under socioeconomic uncertainties. Systematically including transport equity considerations unravels different hotspots that are potentially important in ameliorating transport service inequalities.

Using network science to improve the resilience of transportation networks under seismic hazard
Nazli Yonca Aydin

Transportation networks are backbones of societies in providing everyday services, or after disasters and disruptions. Recently, the behavior of transport networks under disruptions gained attention, calling for more fault-tolerant systems. Resilience is an emerging concept, enabling systems' bouncing back capabilities, which can be framed with four generic functions: resisting within acceptable limits of degradation, re-stabilizing critical functionality, rebuilding up to a sufficient level of functionality, re-configuring the underlying infrastructure. It is important to identify critical functions and locations to improve the robustness, re-stabilizing, re-building capabilities by increasing the emergency response performance and preparedness. In this work, two case studies will illustrate how network science can assist in planning pre and post-disaster recovery actions to increase the resilience of transportation networks. The first case study focuses on using graph-based metrics which are integrated into the stress testing to identify the spatial distribution of critical locations in transportation networks after a natural disaster as well as to compare the network's robustness and efficiency with intuitively resilient networks. The second case study illustrates using a graph-based

connectivity metric to increase re-building and recovery capabilities. In this work, different strategies are used to sequence the damaged segments of the rural road network considering the uncertainty in recovery times. Both methodologies tested on Nepal which was damaged due to the Gorkha earthquake in 2015. These results can illustrate how network science can assist in providing fast and efficient applications for decision makers to prepare emergency management actions and to plan resilient transportation networks.

Transportation and Supply Chain Resilience in the United Republic of Tanzania
Celian Colon, Hallegatte Stéphane, Julie Rozenberg

The economy of the United Republic of Tanzania is growing fast but remains vulnerable to disasters, which are likely to worsen with climate change. Its transportation system, which mainly consist of roads, often get disrupted by floods. How could the resilience of the transportation infrastructures be improved?

We formulate a dynamic agent-based model which combines two different approaches: network criticality analyses and input–output tables. The model uses spatially explicit data to disaggregate production, consumption, and supply chains. It allows us to simulate the disruption of transportation infrastructures, their direct impacts on firms, and how these impacts propagate along supply chains and lead to losses to households.

Indirect losses generally affect people that are not directly hit by disasters. Their intensity nonlinearly increases with the duration of the initial disruption. Supply chains generate interdependencies that amplify disruptions for nonprimary products, such as processed food. We identify bottlenecks in the network. But their criticality depends on the supply chain we are looking at. Some infrastructures are critical to some agents, say international buyers, but of little use to others. Investment priorities vary with policy objectives, e.g., improve food security, promote trade competitiveness.

Resilience-enhancing strategies can act on the supply side of transportation, by improving the quality of targeted infrastructure, developing alternative corridors, building capacity to accelerate post-disaster recovery. On the other hand, policies could also support coping mechanisms within supply chains, such as sourcing and inventory strategies. Our results help articulate these different policies and adapt them to specific contexts.

Ensuring a Resilient Road Network in the Western Balkans with Deeply Uncertain Natural Hazards
Kelly Klima, Craig Bond, Miriam Marlier, Robert Lempert, Monika Crouse, Peter Bar, Jennie Topham, Michael Green

The strategic road network in the Western Balkans, like many infrastructure systems and networks in numerous developed and developing countries, faces the critical challenge of maintaining network connectivity while ensuring resilience in the presence of natural hazards. This talk will introduce the World Bank funded DIVERSION project and decision support tool which enables users to identify road sections that generate the largest risk to the transportation network and prioritize infrastructure investment, subject to a budget constraint, for reducing overall risk. The tool is informed from the Western Balkans VISUM transportation network model and considers a range of frequent and infrequent natural hazards, whose return periods are regarded as deeply uncertain. Sorting algorithms identify those links in the network that generate high risk over a wide range of uncertainty. The analysis employs economic metrics that include estimates of the financial costs of repair, changes in user costs as a result of disruption, and changes in accessibility which, in conjunction with the duration of disruption, should be correlated with larger-scale economic disruption. Risk is measured with several multi-objective criteria, and the decision support tool allows users to explore how different criteria affect the risk rankings. The tool also uses robust optimization algorithms to identify risk-reducing investment options robust over a wide range of deep uncertainty regarding hazard return period and response option cost. The World Bank, for which this tool was developed, plans to use the study and tool to work with its local partners to allocate transportation investment across the Balkans.

Transport risk and resilience analysis under uncertainty
Raghav Pant, Elco Koks, Tom Russell, Jim Hall

Large-scale transport network risks analysis at national scales aims to quantify systemic criticalities and risks due to failures of individual links, highlighting their importance to the entire transport system. These criticalities and risks are measured in terms of increases in the transport costs and widespread macroeconomic losses resulting from loss of access when key linkages fail. When such risks are induced by extreme climactic and weather impacts, the risks are compared with the costs of investing into climate resilience. By quantifying the costs and benefits of climate resilience

options, we can identify locations for prioritizing investments into climate adaptation. Such large-scale analyses depend upon a lot of data on hazards, networks, trade and economic flows, all of which add several layers of uncertainties in the analysis.

By sampling a large ensemble of failure scenarios a computationally intensive approach allows us to estimate failure impacts, but this can get very expensive. Hence to create robust estimates of the risks and costs of climate interventions global sensitivity analysis models and tools, such as SA Lib, are used to quantify the key parameters that drive model results. Crucially they capture the interactions between parameters that drive the analysis and significantly screen out unimportant input parameters to reduce dimensionality.
This presentation shows a national-scale transport risks analysis study done in Argentina to highlight how the transport risks and resilience analysis described above was successfully conducted. To demonstrate the usefulness of such analysis for policy-making, a web-based tool will be showcased.

Moving Towards Adaptive Moving Towards Adaptive Governance for Sustainability under Conditions of Complexity and Deep Uncertainty (Room G)

Chairs & presenters: Zora Kovacic, Silvio Funtowicz, Roger Strand, Dominique Chu

This session is inspired in Antonio Gramsci's reflections: "The crisis consists precisely in the fact that the old is dying and the new cannot be born; in this interregnum a great variety of morbid symptoms appear." The European Union, together with other regions of the world, is currently experiencing a series of economic, ecological, scientific and political crises. Drawing on decades of research in complexity theory and post-normal science, including the ongoing EU Horizon 2020 project "Moving towards Adaptive Governance in Complexity: Informing Nexus Security" (MAGIC), we argue that the crises are strongly intertwined. Furthermore, we argue that the crises are deeply connected to a model of governance that fails to appreciate the complexity of socio-ecological systems and the deep uncertainty that results from this complexity.

There are many useful typologies of uncertainty and complexity. In this session, we shall emphasize the importance of pre-analytical choices on the framing of policy or governance issues – so-called policy narratives – on the definition of the system to be modelled. While such pre-analytical choices are clearly normative, they have profound implications for the science to inform policy and governance. We shall outline our considerations on how to move towards more adaptive forms of governance that deal with such normative choices in a politically and scientifically robust way. A possibly controversial aspect of such considerations is that they appear to have implications not only for scientific methodology but also societal choices such as the choice of policy for economic development. Indeed, it seems that a careful consideration of conditions of complexity and deep uncertainty points towards fundamental tensions between the goal of sustainability and the goal of perpetual economic growth.

Format: Panel Discussion

Decision Making Under Uncertain Sea Level Rise: A Special DMDU Case? (Room A)

Chair: Marjolijn Haasnoot, David Behar, Judy Lawrence, Natasha Barlow, Goneri Le Cozannet, Tim Reeder, Detlef Stammer

Exploring the effects of adaptation strategies on population migration under uncertain sea-level rise
Lena Reimann, Bryan Jones, Claudia Wolff, Athanasios Vafeidis

The socioeconomic impacts of sea-level rise (SLR) will largely depend on the type and efficiency of adaptation strategies pursued, or the lack thereof; and will therefore determine the number of people who will have to migrate due to SLR. In this study, we explore the effect of three adaptation scenarios – 1) 'build with nature', 2) 'hold the line', 3) 'do nothing' – on migration, using a spatial population downscaling model calibrated to the Mediterranean region. We develop assumptions for each adaptation scenario based on the socioeconomic developments described under the Shared Socioeconomic Pathways (SSPs), including the orientation and efficiency of adaptation policies (e.g. sustainable versus engineered), the characteristics of different adaptation strategies (e.g. managed retreat versus protection), and the locations where strategies are implemented. Combining these adaptation scenarios with a range of SLR scenarios, accounting for likely (50th percentile) as well as high-end SLR (95th percentile), we produce spatial population-distribution projections from

2010 to 2100 . Our results offer insights into plausible long-term effects of adaptation strategies on migration by exploring the uncertainty space of future socioeconomic and climatic conditions. We anticipate that our findings can provide a suitable basis for decision -making, for example in regional development planning, by providing first-order estimates of the number of people that have to migrate due to SLR and to the type of adaptation strategies pursued, by pointing to the locations that they will migrate from, and those they will migrate to.

Test of introducing a policy pathway approach to sea level rise in municipal planning in Sweden
Riitta Raty, Annika Carlsson Kanyama, Christoffer Carstens, Karin Mossberg Sonnek, Per Wikman-Svahn

In this paper we reflect on our findings about obstacles and opportunities in introducing an uncertainty embracing approach in municipalities to handle the large uncertainties related to sea level rise. A simplified method based on policy pathways was tested in comprehensive and detailed planning for coastal municipalities in Sweden, as an alternative to the common used planning guideline of one upper limit of sea level rise by 2100.

We will present results from three interventions were we have employed an approach to decision-making under uncertainty into municipal planning based on dynamic adaptive policy pathways. The method was inspired by DAPP and CRIDA and adapted to meet the context in the municipalities. The approach was based on three assumptions: 1. Embracing uncertainties by taking into account the relevant types and full ranges of uncertainties. 2. Using a bottom-up process that starts from the specific decision context by analyzing the consequences of different options. 3. Finding solutions that are robust in that they reduce vulnerability to uncertainty.

All interventions were performed in planning contexts were current and future buildings and infrastructure were to be protected from sea level rise. In each municipality, a group of stakeholders worked with the researchers during three workshops. In the last workshop policy pathways were created, showing alternative ways to protect the chosen area over time given various sea level rise scenarios, including high-end scenarios up to year 2200.

UK contribution to Decision making under uncertain sea level rise: a special DMDU case
Tim Reeder, Jason Lowe, Natasha Barlow, Ivan Haigh

The contribution to discussion on Decision making under uncertain sea level rise: a special DMDU case will draw from three key initiatives in the UK.

Firstly there is current research into how confidence and opinion in the science community can be systematically assessed in exploring extreme high end sea level rise scenarios. This is being carried out led by the UK Met Office, University of Leeds and Southampton University. Key emerging findings will be discussed which could help inform how high end sea level rise scenarios feed into Adaptation Pathway (AP) development and decision making.
Secondly work is going ahead to develop APs in Somerset England addressing not only sea level rise, but also interlinked issues such as fluvial flooding, heat and health. This work is supported by the Interreg CoAdapt project. This is the first UK example outside of London to look at the wider implications of high end sea level rise scenarios. The exercise is being carried out at a high level with key stakeholders and comparisons can be made with experience elsewhere with more detailed bottom up analysis.

Thirdly a standard / guide for APs and decision making is being developed by BSI, which could help inform any forthcoming international standards following ISO 14090 which are addressing climate change adaptation. The session will update progress including the need to consider high end scenarios.

Reflecting on highly uncertain sea level rise and the use of DMDU approaches: experiences from the Netherlands
Marjolijn Haasnoot, Ferdinand Diermanse, Jaap Kwadijk, Bart van den Hurk, Dewi Le Bars, Jos van Alphen

Recently, the Dutch government stress-tested their adaptive plan to new insights on potential but highly uncertain accelerated sea level rise as a result of ice mass-loss from Antarctica. The study concluded that even for a well-protected developed country such as the Netherlands, the projected rate of change and increased uncertainty bandwidth has large implications and could be a gamechanger for the current protect-and-pump strategy. Besides mapping uncertainties and scenarios, the study recommended to further investigate consequences, monitoring to derive timely and reliable signals, and alternative strategies to adapt to multi-meter sea level rise. Here, we reflect on the process and discuss how approaches for decision making under deep uncertainty, such as pathways, signal monitoring, tipping points and scenarios,

supported this process and may continue to do this in the future, not only in the Netherlands but also in other low-lying deltas and coastal zones. For example, confronting the adaptation pathways of the present adaptive plan to high rates of sea level rise showed that the pathways should not just be implemented more rapidly. Instead, some of the actions are better omitted because of reduced lifetime at high rates of sea level rise, and alternative actions and strategies are needed. To identify alternative strategies we have explored the solution space for adaptation to low to high sea level rise, and will present initial results.

Innovations for Scenario Discovery when Seeking Dynamic, Robust, and Resilient Action Pathways (Room I-J)

Chair: Patrick Reed, Jan Kwakkel, Jon Lamontagne

Behavior-based scenario discovery

Patrick Steinmann, Willem Auping. Jan Kwakkel

The use of (multi-)model ensembles for planning and policy-making is well known in climate science and meteorology. One method of model-based decision support, known as 'scenario discovery', focuses on analyzing model ensembles to identify common properties.

Scenario discovery starts from a model of the system of interest, and its key uncertainties. Computational experiments covering the uncertainty space are conducted, creating an ensemble of model runs. A classification is imposed on the ensemble using exogenous criteria. Finally, a rule induction algorithm is used to associate different classes of outcomes with specific subspaces in the uncertainty space.

Scenario discovery commonly focuses on outcomes which do not meet policy objectives at the end of the model run. By considering a single point in time, dynamics are ignored. However, different dynamics represent distinct vulnerabilities, requiring different responses. This is particularly likely for non-linear systems.

We propose behavior-based scenario discovery, a novel approach to identifying decision-relevant uncertainty subspaces based on model dynamics. Rather than using an external criterion to classify the model runs, model behaviors are partitioned using time series clustering. Then, rule induction is applied to demarcate the uncertainty subspace from which each cluster originates, thus identifying input conditions that constitute distinct policy vulnerabilities.

We demonstrate behavior-based scenario discovery on a non-linear system dynamics model on climate mitigation and energy prices. We find that behavior-based scenario discovery can identify input subspaces associated with distinct model behaviors. Furthermore, a subset of "major" input uncertainties with significant influence on output behavior can be determined.

Premortem and DMDU: separated by a common purpose

James Maltby, Gareth Conway, Jim Maltby

DMDU approach is routinely described as deliberation with analysis. There has been much intellectual study on the analysis side of the 'deliberation with analysis'. Within the DMDU community, the emphasis appears to have been on analysis. However, in other communities have explored areas of deliberation considerably. We believe that it would be incredibly useful to compare the DMDU community with other areas, for future use, and to enable joint working.

For instance, we have noted a similarity in the 'reverse analysis' approach (the 'monitor and adapt' as opposed to the common 'Predict-then-act' approach) between RDM and the philosophy underpinning the PreMortem analytic technique, developed by the Macrocognition research community.

The PreMortem is an approach that imagines that a plan, project or organization has failed (candidate strategy), and then works backward to determine what potentially could lead to the failure of the candidate strategy by reframing it many times (using multiple scenarios). The list of potential failures is then used to identify ways to strengthen the candidate strategy and is then iterated to test against further failure.

Also, he Premortem is one of the few approaches (we know of) to have good evidence demonstrating an increase in performance in decision making resulting from its use. There are also good examples of its use e.g. planning the capture of Osama Bin Laden.

Exploring the similarities between the two could bring two different communities together, aid fluency in new participants to DMDU tools and infer evidence in support DMDU performance in decision making.

Increasing adaptation in urban planning. An adaptation pathways approach to mitigate the hydrological risk in the X Municipality of Rome.
Simona Mannucci, Jan Kwakkel, Hedwig Van Delden

In the X Municipality of Rome over 91.600 people live in high hydrological risk areas. The lack of policy regulations over the past thirty years affected the urban tissue and its components, building types, open spaces and functions, mixing formal and informal settlements that cannot cope with flooding. The drainage system was designed for lands with agricultural vocation and the cost of securing the area with a properly dimensioned system is over 150 million euros.

Different uncertainties affect the development of the region, including not only the changing climate, but also the possible implementation of changes to the infrastructure system and the construction of a sport stadium and business center in adjacent districts. Whether and when these developments might happen is deeply uncertain, but if they happen could strongly affect the way the urban tissue changes.

This study investigates possible adaptations of the urban tissue, to reduce the impact of flooding, given the uncertainty about future climate and infrastructural and land use developments. A qualitative approach based on historical data has been used to conceptualize the interplay between flooding and land use change. This conceptualization is formalized in a land-use change model using Metronamica. We explore the dynamics of land use change in X Municipality up to 2050 taking into account various possible modifications that could reshape the urban structure. The next step includes a robust decision-making approach to structure adaptation pathways, stressing candidate adaptation actions that could be taken, with a focus on short-term action and long-term options.

A Scenario Discovery Approach for Designing Dynamic, Robust Adaptive Strategies: Optimization and Machine Learning Algorithms for Estimating Critical Thresholds and Adaptation Options
Edmundo Molina, David Groves, Steven Popper

Robust Decision Making (RDM) and other related DMDU methods often use exploratory modeling and scenario discovery techniques to identify vulnerabilities of leading strategies, decisions, or policies. This information then guides the development of strategies that are robust, or avoid the identified vulnerabilities in a reasonable way. To date, the linking between vulnerabilities and adaptation has been based on expert judgement, as is done to create subway-style adaptive pathway maps, or simple quantitative rules that link signposts and thresholds to the implementation of additional actions, often instantiated in a decision tree.

This talk will present recent work developing a robust water management strategy for the city of Monterrey, Mexico, which used a new approach for developing adaptive, dynamic decision trees that directly connect a systems vulnerabilities to adaptive management. This approach combines optimization and machine learning algorithms to estimate dynamic strategies based on statistical evidence inferred from exploratory modeling ensembles. Through optimization, short term options lying on the Pareto Frontier of cost and reliability regret are identified. Then through successive optimization and the applications of decision rule classifier algorithms, adaptive strategies are estimated for each of the options lying along the Pareto Frontier. The application of this analytical framework shows that although all estimated dynamic strategies significantly reduce vulnerabilities by adapting to unfolding future conditions, these strategies differ greatly in terms of their cost, the factors that trigger new investments and their capacity to absorb stressors, which are important attributes to be considered in the design of robust, adaptive strategies.

A Decision Capability Framework: Matching Decision Capabilities to Decision Support Approaches to Make More Effective Decisions in Deep Uncertainty (Room G)
Chair: Katy Roelich, Mark Workman and Muriel Bonjean Stanton

From root to crown: Exploring the fit between capabilities and robust decision support approaches at different decision levels in forest management
Roderich von Detten, Naomi Radke

Forest management has, by tradition, shaped the concept of sustainability and on that basis has a very characteristic periodic inventory and planning system. Management knowledge is largely founded on experiences but these are devaluating rapidly due to deeply uncertain climate change: Changing growth conditions and an increasing number of severe risks (such as natural hazards), which become more

and more unpredictable, make the task of protecting and managing forest ecosystems even more complex.
While scientific advice, mainly via modelling, claims to provide decision support under specific conditions and with selected parameters, time scales and spatial scale, the nature of the problem is different than for forest managers/ decision makers, who face the threats of multiple risks, legitimization problems, irreversibility and unforeseeable long-term consequences of current decisions.

Against this background, the presentation contrasts robust decision support from science/ modelling with practical forest management and planning capabilities on different decision making levels in order to elaborate scope and fields of application, as well as related problems, shortcomings & deficiencies. After explaining the crucial decision fields and capabilities in forest management with regard to its particular temporal, spatial and content-related scale and the requirements of different organizational levels, examples of robust decision making applications in forestry and the information they can provide descriptively and visually are presented. The match between decision support and decision capabilities is evaluated with regard to the aforementioned scales of time, space, and content in order to assess the potential contribution of robust decision support models.

Logistics Decision Capabilities and Support Approach Towards Effective Decision in Nigerian Health System: A Study of Tertiary Health Facilities.
Francis Andem

Effective planning and management of healthcare resources in the Nigerian health sector is becoming more and more complex. The capabilities of individuals and organizations in this sector to make effective and efficient logistics decision in the face of growing uncertainty is becoming even more complex. Thus, there need for careful study and understanding of the state and morphology of the different logistics decisions required by the health facilities. And the ability of the individuals and organisations involve addressing these complex scenarios. The study seek to create a decision support system that will enhance the decision capabilities of individuals and organization towards a more effective logistics decision in the face of growing uncertainty. This study is on going and I seek to adopt DMDU model to create the Decision Support System.

Abstracts: Day 2
Thursday, 7 November 2019

The use of data and information for decision making in humanitarian crises (Room I-J)

Chair: Tina Comes
Speakers: Juriaan Lahr, Marc van den Homberg, Freek Huthoff, Stuart Campo, Kashif Nadeem Muhammad, Olga Aymerich, Philippe Ker Rault

Growing water demands combined with climate change may lead to increasing pressures on particularly agriculture and related livelihoods, which can result in (forced) migration, conflicts, and humanitarian crises. Possibilities rapidly increase to obtain information on imminent crises or disaster risk from global data sets, including Earth Observation Systems. And while it is widely recognized that understanding the most prominent risks in time to plan and implement adequate response can save lives – information needs to address the situation on the ground and respect decision cycles, hierarchical levels, workflows and processes. The humanitarian sector has dedicated principles and requirements with regard to, amongst others, content, timing, format, protection/privacy and accessibility.

In this session, we explore the use of water information to inform humanitarian responders in order to develop a research agenda. Through two case studies, the recent flood in Mozambique and water-related human displacement in Iraq, we investigate water-related information use and information needs in the humanitarian domain. We specifically will reflect on
• Tensions between short-term responsive decision-making and long-term disaster risk reduction, resilience and planning
• Uncertainties, tipping points and intervention windows
• Institutional and organizational requirements and barriers to sharing and using information
• Implications of humanitarian principles and related values and norms for information sharing and decision-making

Session Format
In this interactive session, we aim to foster exchange between invited humanitarian experts and the audience to explore selected problems derived from the cases. The invited humanitarian experts from UN-agencies and INGOs, will reflect on their experiences with respect to decision-making under deep uncertainty. Using a fishbowl format in two rounds of discussion, we will identify drivers of uncertainty in decision-making at different geographical and temporal scales (global vs. local and long- vs. short-term), and derive requirements for the application of DMDU-methods related to intervention windows, decision-making processes and coordination structures. Then, we will discuss how different scales and levels influence each other, and derive an agenda for future research.

Innovations for Scenario Discovery when Seeking Dynamic, Robust, and Resilient Action Pathways (Room A)

Chair: Patrick Reed, Jan Kwakkel, Jon Lamontagne

Defining robustness, vulnerabilities, and consequential scenarios for diverse stakeholder interests within the Upper Colorado River Basin
Antonia Hadjimichael, Julianne Quinn, Erin Wilson, Patrick Reed, Leon Basdekas, David Yates, Michelle Garrison

The Colorado River is the largest river in the southwestern United States, supporting municipal, industrial, agricultural, and recreational activities worth an estimated $300 billion/year within the state of Colorado alone. While the Upper Colorado River Basin (UCRB) lies west of the Continental Divide, most of this activity takes place east of the Divide, where 80-90 percent of Colorado's population resides. Consequently, major diversions of water across the Divide are necessary, while at the same time, the activities of agricultural stakeholders need to be supported within the basin. Amidst a historic 18-year drought and increasing competition for water, Colorado State planning efforts must carefully consider how to balance the competing needs.

This study supports the State's decision-making efforts by assessing the vulnerabilities faced by the various stakeholders in the UCRB as a result of changes in climatic extremes, demand growth, as well as in the institutional and physical infrastructure in the basin. We are seeking to better understand the impacts of these uncertainties on the basin's ability to meet both environmental flow requirements and demands for hundreds of irrigation and municipal stakeholders. Our analysis reveals that stakeholders of varying sectors, water right seniority, and demand experience vastly different impacts, regarding the timing, magnitude, and frequency of shortages. Furthermore, these impacts are driven by different sets of changes and uncertainties. This work will be used to inform adaptive user- and scenario-specific conservation and management efforts to tackle drought in the basin by leveraging emerging patterns in the sensitivities of different stakeholders.

Consequential Compromises: Exploring the Cooperative Stability of Multi-Actor Robustness Compromises in Regional Infrastructure Investment Pathways
David Gold, Bernardo Trindade, Patrick Reed, Gregory Characklis

Water utilities across the world face the challenge of long-term infrastructure planning under deeply uncertain future conditions stemming from climate change, population growth, financial stress, and resource competition. Recent work has highlighted planning strategies that utilize regional coordination and planned adaptation to design cooperative and dynamic infrastructure pathways that are robust to deeply uncertain futures. Regional cooperation allows water utilities to utilize water supply infrastructure more efficiently, potentially delaying or alleviating the necessity of supply expansion. However, cooperative coalitions with asymmetries in risk exposure, available resources or political power may be subject to robustness conflicts between the regional actors, undermining coalition stability and posing institutional vulnerabilities to investment pathways. This study contributes a novel application of scenario discovery to navigate robustness conflicts in complex multi-actor systems. Our approach first draws on concepts from cooperative game theory to quantify the stability of planning alternatives and select potential compromise solutions. We then apply machine learning algorithms to discover the drivers of regional robustness conflict and identify strategies for conflict resolution. Our methodology is demonstrated on a system of four water utilities in the Research Triangle of North Carolina that are investigating cooperative water supply planning strategies through 2060. Results demonstrate that the stability and vulnerability of cooperative infrastructure pathways are fundamentally shaped by how robustness conflicts are addressed. Results from this study are broadly applicable to water supply as well as analogous infrastructure investment applications in other areas such as

stormwater management and transportation systems planning.

Coordination and control: Limits in standard simulation-based vulnerability assessments of complex multi-reservoir systems
Charles Rougé, Patrick M. Reed, Danielle Grogan, Shan Zuidema, Alexander Prusevich, Stanley Glidden, Jonathan Lamontagne, Richard B. Lammers

Model-based vulnerability assessment for hydrological extremes needs to consider the interactions between the many stakeholders in a river basin, as well as the institutions and regulations that mediate them. Unfortunately, commonly employed representations of human-operated structures have a limited ability to capture human-mediated coordination and control actions in complex river basin systems. This study contributes a detailed diagnostic analysis of the parametric controls and their effects in standard reservoir representations in flood and drought modeling. Our diagnostic analysis uses the Water Balance Model (WBM), which features detailed representations of the human infrastructure coupled to the natural processes that shape water balance dynamics. Our analysis focuses on challenges posed by human-mediated coordination and control processes using the multi-reservoir cascade of the Upper Snake River Basin (USRB) in the Western U.S. We employ a time-varying sensitivity analysis that utilizes Method of Morris factor screening to quantify how the parametrizations of the reservoir release rules impact flows throughout the USRB. Our results are compared with historical operations, and demonstrate the importance of understanding the state-space context in which reservoir releases occur and where operational coordination plays a crucial role in avoiding or mitigating water-related extremes. Understanding how major infrastructures are coordinated and controlled in major river basins is essential to properly assessing future flood and drought hazards. This implies that the validation of hydrological model for this purpose should move beyond the usual goodness-of-fit checks of outlet flows to incorporate an assessment of the actual emergency response operations used to mitigate hydrological extremes.

Using the scenario discovery approach to identify winners and losers of adaptation policies under uncertainties
Bramka Arga Jafino, Jan Kwakkel

Climate-induced inequality arises from both the spatially distributed physical processes of climate change and the implementation of adaptation measures. To apprehend inequalities, we propose to utilize scenario discovery techniques to identify inequality patterns arising from implementation of adaptation measures under uncertainties. Scenario discovery has been traditionally used to illuminate combinations of uncertainties that lead to (un)desired outcomes. The technique maps model outcomes (the 'M' within the XLRM framework) to uncertainties embodied in input parameters (the 'X' within the XLRM framework). In climate change adaptation, however, different inequality patterns may emerge from interactions between the adaptation measures taken (the 'L' within the XLRM framework) and the exact way in which uncertainty is playing out. Therefore, to identify winners and losers (i.e., inequality patterns), we modify the use of scenario discovery to map 'M' not only to 'X', but also simultaneously to 'L'.

We apply this approach for model-based adaptation planning of rice farmers in the Vietnam Mekong Delta. We evaluate a number of pre-specified adaptation measures. The aggregate profit of the farmers at a district level is used as the performance measure, resulting in a total of 23 model outcomes. After running the experiments, we cluster the simulation results based on the patterns of winners and losers across the 23 districts. Afterward, we apply scenario discovery to map combinations of uncertainties and adaptation measures to the clusters of inequality patterns. Understanding winners and losers helps decision makers in preparing additional compensation or redistribution measures, hence promoting fairness in climate change adaptation.

Institutions And Governance Arrangements Enabling Forward-Looking Decisions Under Uncertainty By Governments (Room G)
Chair: Wieke Pot, Art Dewulf, Judy Lawrence

Protecting and representing the interests of future generations in policy making
Samuel Hilton

Long-term issues are often neglected from the political agenda in favour of urgent matters. However, these issues – like climate change, public health trends and catastrophic and existential risks – have potentially widespread ramifications for the future of the UK and beyond.

The All Party Parliamentary Group (APPG) on Future Generations aims to create space for cross-party dialogue on combating short-termism and to identify ways to internalise longer-term considerations into today's policy decision making.

The APPG is now:
• Supporting Parliamentarians advocating for the representation of future generations in UK policy. Including researching the potential mechanisms for representation.
• Carrying out an inquiry into UK policy to investigate where long term thinking happens well, where it is failing and why. We will be looking into policies related to UK poverty, cyber-security and other topics.

We are already reaching conclusions on how to build a system that supports long term thinking in the UK, including the role of a commissioner for future generations, the use of foresight by policy makers, the use of discount rates, and so forth. We would present on our thinking to date and our suggestions of how liberal democratic governments can create systems to improve long-term thinking in policy and political processes.

Balancing equity and efficiency in adaptation to climate change: Decision-making on resource allocation at the city scale
Hanne van den Berg

As the need to make cities climate-resilient becomes more urgent, decisions about how to allocate adaptation resources have become increasingly important. For instance, should decision-makers fund a sea wall to protect a larger community, provide subsidies to property owners to raise minimum floor heights to avoid flooding, or consider relocating a neighborhood to accommodate increased river discharges? Making these choices means considering both efficiency and equity: the former approached through benefit-cost analyses, the latter through investigations of the distributional effects of climate change responses and access to decision-making processes. Though questions of who benefits and who is burdened are central in all public policy decisions, climate change adaptation forms a particularly challenging context due to its conditions of high urgency, deep uncertainty, conflicting notions of justice and stakeholders' valuation of risk and prioritization of objectives.

Given this complexity, resource allocation decisions must be robust, forward-looking and transparent. In city settings in particular, where many adaptation efforts currently concentrate and socio-economic inequalities are increasingly acute, city officials need a strong set of tools and frameworks for equitable decision-making. This paper first explores conceptual approaches to decision-making that aim to address the challenges of the climate change context and then views these approaches through the lens of a comparative case study of the United States and the Netherlands. This analysis aims to open avenues to future research on urban decision-making processes within the context of dynamic and uncertain social, economic and environmental settings.

Assessing the adaptive capacity of peri-urban institutions as part of an adaptive pathways approach for water management in India
Sharlene L. Gomes, Leon M. Hermans

Water insecurity is affecting peri-urban areas of Indian cities. Peri-urban areas are where the rural to urban transition is visible from changes in land use, economic activities, and population. The dynamic nature of these areas and future uncertainties require an adaptive approach to water management. Underlying institutions, defined as societal rules for societal interaction and decision-making, play an important role in this regard. Understanding the extent to which existing institutions support adaptation and long-term resilience is the starting point for designing pathways for future development.

This research discusses the adaptive capacity of institutions in peri-urban case studies near Kolkata. First, water related vulnerabilities concerning livelihoods and domestic water needs are identified. Next, the adaptive capacity is examined through an institutional lens, assessing how actors respond to these vulnerabilities both formally and informally. The capacity for long-term resilience is examined through a set of resilience indicators that are either supported by or constrained by the overarching institutions.

The insights from this study will feed into the design of stakeholder workshops where government agencies and local communities co-develop future adaptive pathways as part of a transformation towards more sustainable and resilient communities. This research thus helps peri-urban stakeholders consider their existing institutional context in planning for possible futures during the urban transition process. It highlights the value of preparatory activities

along the institutions and governance dimensions, when using the adaptive pathways approach with peri-urban stakeholders.

Bridging Two Approaches for Sustainable Development: Decision Making under Deep Uncertainty (DMDU) and Transition Management (TM)
Shirin Malekpour, Warren Walker, Fjalar de Haan, Vincent Marchau, Niki Frantzeskaki

Sustainable development is a long-term endeavour involving deep uncertainty, immense complexity, and requiring transformative change at multiple scales. To navigate such a grand challenge, new processes and approaches have been developed across various academic fields, including Policy Analysis and Sustainability Transitions. Two prominent approaches to long-term planning within these two fields are Decision Making under Deep Uncertainty (DMDU) and Transition Management (TM). One key question in relation to sustainability that concerns them both is how to make the necessary changes happen in practice. While DMDU provides analytical concepts and tools to prepare for change, TM offers a transformative governance approach and a participatory process to enable change. We argue that sustainable development could benefit from an explicit cross-fertilisation across the two approaches. We will highlight the key commonalities and differences between the two approaches, and reflect on potential cross-connections. We argue that DMDU can benefit from the participatory process focus of TM, which helps to mobilise a range of actors and to build networks and coalitions for social and environmental change. DMDU can also learn from some of the governance instruments offered by TM, such as visioning, experimentation, reflexivity, and social learning. TM, on the other hand, can be enriched by the analytical concepts and tools developed by and widely used in DMDU, such as adaptive pathways, triggers and signposts, exploratory scenarios, and exploratory modelling. An illustrative case study will be used to demonstrate what a cross-connection between the two approaches might look like.

Uncertainty and credibility, Experience in supporting a local institution in Benin aimed at dealing with (deep) uncertainty.
George de Gooijer, Maman Daouda

We would like to present the experience from the national water institute of Benin, that has been existing now for 8 years, from an initial idea in April 2011 to a functional institute where various existing valuable functions from the university were combined and new elements were created. Still the institute has to struggle to stay afloat.

Essential elements for a functioning institute seem to be: mandate, funding, certified quality and a dynamic governance structure.

The presentation will go into the timeline of the institute, the results and experiences so far, and the role outsiders have played and could play in the performance of the institute and its position in local, regional and global debates. This outsider role would include securing the credibility of the institution.

Practical Challenges In The Application Of DMDU Methodologies To Climate Risk Assessment And Management (Room A)

Chair: Ad Jeuken, Umit Taner, Casey Brown, Patrick Ray

Mainstreaming DMDU approaches into water resources practices - The DTF experience
Diego J. Rodriguez, Homero A. Paltan, Luis E. Garcia

Among key sources of uncertainty facing water planners and designers, climate change has received increasing attention at the World Bank (WBG) during the past decade. Unsatisfied with prevailing top-down scenario-led methods relying mostly on downscaling Global Climate Models (GCMs), the WBG turned to DMDU approaches to evaluate vulnerability, robustness and resilience beyond economic indicators for project selection and prioritization. DMDU approaches were applied to specific cases, adapting research results with collaborating academic and consulting institutions. However, the WBG as an operational organization needs to mainstream these approaches in its regular investment selection protocols. This presentation illustrates these challenges using examples from the lessons learned during the application of one of these tools-the Decision Tree Framework (DTF)- piloted in Nepal, Kenya, Indonesia, Mexico, and Peru, involving hydropower, water supply, irrigation, flood control, and river basin planning cases. The DTF is a bottom-up tool using a Decision Scaling step-by-step four phase decision-making approach that deepens the level of analysis as needed by the perceived vulnerability of the project at each step. Although successful, several challenges persist such as how to

adequately represent land use changes, water quality, social issues including equity, as well as O&M and other non-climate stressors while combining them with climate variables. Above all, the presentation looks to discuss the non-trivial challenge of scaling DMDU approaches to operational practice, incorporated as a component of normal pre-feasibility or feasibility studies at a cost, time and effort commensurate with such studies, in a practitioner-friendly format and yet, keeping its scientific sustenance.

A streamlined approach to applying DMDU methods for climate-resilient infrastructure planning - Lessons from Mendoza, Argentina
Michelle Miro, David Groves, James Syme, Alejandro Becerra, Guillermo Cúneo, Juan Andrés Piña, Adrien Vogt-Schlib, Valentina Saavedra Gomez

The application of DMDU methods to climate resilient water infrastructure planning necessitates collaborative engagement with various local partners as well as sufficient time and resources. Such resources and engagements are needed to correctly frame planning challenges and goals, define uncertainties, characterize and obtain models and data, evaluate systems under uncertainty and analyze results, and develop and deliberate over a set of adaptive planning solutions. Recently developed screening frameworks mentioned in the session description suggest that for some applications a complete robustness analysis could be necessary. While there are numerous examples in the literature for how to do such full analyses, these are generally custom-designed, involved, and costly. A more routine application of DMDU methods to ensure the climate-resiliency of infrastructure investments may not require this full treatment. Using lessons from a DMDU study of long-term water planning in Mendoza, Argentina, this talk describes a replicable, streamlined approach to DMDU studies for a range of partner engagement, budgetary, and time availability circumstances. Such approaches would be designed to be implemented in one year with modest funding and would be relevant for use by development banks and jurisdictions looking to support large infrastructure investments. Key features include: (1) using available climate data to stress test existing systems and proposed improvements; (2) identifying vulnerabilities as a means for systematically determining conditions that favor different choices; and (3) engaging stakeholders and decisionmakers in participatory trade-offs analyses to reflect different viewpoints over risks and the costs of improving robustness.

Communicating climate change risk for an investment project in irrigation and flood protection in West Kenya
Marnix van der Vat, Luis Garcia, Johannes Hunink, Homero Paltan, Diego Rodriguez, Dana Stuparu

A climate change risk assessment was carried out for the Lower Nzoia investment project using the Decision Tree Framework (DTF, Ray and Brown, 2015). The DTF involves a stepwise approach that guarantees that the depth of the analysis is coherent with the sensitivity of the project to climate change risks versus other non-climate change related risks. Furthermore, the DTF is a bottom-up approach focusing on the performance of the investment project under a range of future climate change realizations, instead of focusing the analysis on a limited number of scenarios derived from results of Global Circulation Models.

The Lower Nzoia project concerns extension of the irrigated area and improvement of flood protection along the Lower Nzoia in West Kenya. The project is part of the Kenya Water Security and Climate Resilience Program (KWSCRP) supported by the World Bank.

The assessment was carried out using a linked weather generator, hydrological model, water allocation and crop growth model and economic module. The results show that while non-climatic variables may play an important role in the Lower Nzoia investment project, it is sensitive to climate change. Also, the design performs well under the current climate as well as under the most likely future climate conditions. Pathways have been developed consisting of future adaption measures to adapt to drier or substantially wetter conditions.

The usefulness of performance metrics such as robustness, resilience and vulnerability has been evaluated. Different communication material developed for different target groups will be presented together with lessons learned and recommendations.

Incorporating Values In Modelling And Decision Analyses (Room I-J)
Chair: Casey Helgeson, Nancy Tuana

A method selection framework for developing pathways to sustainability under uncertainty
Enayat A. Moallemi, Brett A. Bryan, Shirin Malekpour, Katrina Szetey, Michalis Hadjikakou, Angela M. Rojas, Abdullah

Shaikh, Fjalar J. De Haan, Alex Smajgl, Emily Nicholson, Euan G. Ritchie, Alexy Voinov, Wikke Novalia

The debate on global environmental and societal change has increasingly favoured 'alternative policy pathways' to obtain robust inferences and to analyse trade-offs among global objectives, such as the 17 Sustainable Development Goals (SDGs). Policy pathways are developed in a sequence of iterative and interactive steps: from agenda setting, to exploring future scenarios, to developing and evaluating potential policy pathways, as framed systematically in the Dynamic Adaptive Policy Pathways approach. Various combinations of methods—leading to potentially different outcomes—can be used in each step to develop policy pathways. Computational modelling in an exploratory setting has been considered as a powerful tool in reasoning about pathways to sustainability and for investigating the implications of numerous alternative assumptions. Stakeholder engagement through participatory approaches has been also broadly recognised as a determinant for designing socially robust pathways that draw on a diverse range of values and perspectives. Considering the myriad of available modelling and participatory methods, choosing the appropriate method(s) for any given context becomes a critical task. We suggest a 'method selection framework' that enables researchers to analyse: 1) what alternative methods they can use for drawing robust pathways towards their objectives; 2) what method(s) at each step better suit the problem at hand; 3) when the selected method(s) need to change if a challenge or opportunity arises during the implementation. We look at the method selection process in developing policy pathways towards achieving the SDGs in a local community in the Forrest/Otways in Victoria, Australia, as an illustrative case study.

Operationalizing ethical principles in flood risk management: a case study on the Dutch-German Rhine
Alessio Ciullo, Jan Kwakkel, Karin de Bruijn, Neelke Doorn, Frans Klijn

Flood risk management decisions are often made based on cost-benefit analyses (CBA), where policies are evaluated according to aggregated benefits and costs. CBA, however, is not informative about the distribution of benefits, raising questions on the fairness of the proposed policies.
To address this issue, we propose the use of additional decision criteria that account for benefits distribution. We apply the new decision criteria to identify flood risk reduction policies for the Lower Rhine River. Policies are identified according to alternative problem formulations, reflecting CBA (i.e. only optimizing costs) and egalitarian (i.e. optimizing costs and the new decision criteria) principles. Possible interventions include: embankment heightening, making Room for the River and changing the discharge distribution of the river branches.

Formulations based on solely cost optimization lead to very poor performances at some areas for the sake of reducing the overall aggregated costs. Formulations based on the new criteria have significantly different results based on how these criteria are defined. When risk reduction is distributed equally, very poor economic performances are reached. When risk is distributed equally, results are in line with those of formulations based on cost optimization, but a fairer risk distribution is reached. Decisions on the risk reduction measures to be preferred also differ, with the cost optimization approach strongly using the leverage of changing the discharge distribution (low cost, but substantial effect on risk shifts) and the alternative formulations spending more on embankment heightening and Room for the River, to re-balance inequalities in risk levels.

Climate policy considering heterogenous world views
Sara Turner, Lisa Rennels, Robert Lempert, David Anthoff

Two fundamental attributes of our world include heterogeneity and deep uncertainty. The former represents the irreducible diversity of priorities, goals, and values that exist among and within different communities. The latter represents an irreducible uncertainty regarding the consequences of our actions. Both fundamentally shape society's response to climate change. This talk employs DMDU methods and the FUND (Framework for Uncertainty, Negotiation and Distribution) integrated assessment model (IAM) to offer an initial examination the implications of heterogenous world views on the choice of national and international climate policies. In this context world views consist of differing clusters of expectations, objectives, and acceptable policy options. Considering two major Paris signatory countries, India and the United States, we compare the impact of divergent beliefs and values across three distinct population subgroups on identified carbon costs. Relying on survey data from the US and India conducted by the Yale Program on Climate Change Communication, we select three distinct population subgroups and derive worldviews for each that identify key uncertainties, objectives, and assumptions about policy impact. Using the FUND IAM, we identify pareto satisficing surfaces for each worldview that can be compared to

identify points of overlap or divergence. We focus on two types of stylized policies: national carbon prices and adaptation to sea level rise. Results demonstrate an approach for considering heterogenous world views in DMDU analyses and suggest the value of considering such heterogeneity in climate-related decision support.

Trust and values at the science-policy interface
Marina Baldissera Pacchetti

I argue that theories of trust can clarify the role of value judgements in the interaction between scientists and policy makers regarding climate science and uncertainty. Theories of trust are a social science tool for analyzing the trust relations between individuals (interpersonal trust) and between organizations (organizational trust). After describing the key differences between the procedural and structural characteristics of science and policy making, I explore some of the main ideas of theories of trust. Different forms of trust (procedural, affinitive, dispositional, rational) describe the trust relationship that develops between policy makers and scientists. I suggest that these forms of trust help identify what value judgements enter the decision-making process at the science-policy interface. A breakdown in trust can damage the relationship between scientists and policy makers, and I discuss a breakdown in procedural trust, a form of trust that arises from the trustor's reliance on the rules of knowledge production of the trustee. The trustor is usually an individual, and the trustee can be either an individual or an institution. The breakdown can result from a misalignment of value judgments in knowledge co-production, which is a misalignment in epistemic value judgements, and from differences in incentive structures for scientists and policy makers. The difference in incentive structure can influence epistemic and ethical value judgements of both scientists and policy makers. Finally, I suggest that deep uncertainty is a special case of breakdown in procedural trust that arises from a misalignment of value judgements about what counts as reliable

Finding The Tipping Point - Deep Uncertainty For Resilience Engineering In Coupled & Complex Systems (Room G)
Chair: Tina Comes, Tatiana Filatova

Lifelines: the resilient infrastructure opportunity
Stephane Hallegatte, Jun Rentschler, Julie Rozenberg

This book lays out a framework for understanding infrastructure resilience and makes an economic case for building more resilient infrastructure. Building on a wide range of case studies, global empirical analyses, and modeling exercises, it provides an estimate for the impact of natural hazards on and through infrastructure, looking not only at repair costs but also at the consequences for users, from households to global supply chains. It also reviews available options to make infrastructure assets, systems, and users more resilient and better able to cope with natural disasters. It finds that investing in more resilient infrastructure is robust, profitable, and urgent. Investing in more resilient infrastructure is beneficial in 96 percent of thousands of scenarios exploring possible future socioeconomic and climate trends. In the median scenario, the net benefit of investing in more resilient infrastructure in low- and middle-income countries is $4.2 trillion, with $4 in benefit for each $1 invested. Climate change makes action on resilience even more necessary and attractive: on average, it doubles the net benefits from resilience. And because large investments in infrastructure are currently being made in low- and middle-income countries, the median cost of one decade of inaction is $1 trillion. The report concludes by identifying five obstacles to resilient infrastructure and offering concrete recommendations and specific actions that can be taken by governments, stakeholders, and the international community to improve the quality and adequacy of these essential systems and services, and contribute to more resilient and more prosperous societies.

The uncertainty space in urban planning
Supriya Krishnan, Tina Comes

Cities today are getting increasingly complex. 70% of cities are dealing with the effects of climate change, and nearly all are at risk. Therefore, urban planners need to integrate long-term planning goals (for mitigating or adapting to climate change) into shorter-term planning decisions to accommodate for this unprecedented growth and impacts on infrastructure systems.

Planning methods from the DMDU-community have proven useful for policy-making for specific infrastructures or hazards. To facilitate long-term urban planning, they must address:

(1) Complexity: Cities constitute coupled socio-technical-environmental decisions. Urban planning methods must

therefore concurrently account for multiple infrastructures, hazards, political, social and environmental dynamics.
(2) Time pressure: The planning process for cities is under constant pressure to address urgent developmental needs. To overcome the myopic nature of current planning, methods need to be developed that provide short-term solutions that can factor in climate risks for the longer run.

The complexity of cities combined with time pressure forestalls a full exploitation of the uncertainty space via traditional DMDU methods. What is needed is a method for urban planners to systematically explore the uncertainty space and identify key criteria and tipping points that influence planning. Using literature from academia and practice, this study makes a headway in this direction by mapping state-of-the-art strategies for urban planning in resilience and climate adaptation and evaluate them to:
(i) Identify gaps in urban planning for resilience;
(ii) analyse DMDU's potential to fill these gaps; and
(iii) explore concrete avenues for DMDU methods to be introduced into urban planning.

Using surrogate models to analyse resilience of ABMs
Guus ten Broeke, George Van Voorn

A wide range of mechanisms underlie resilience of complex adaptive systems. These include spatial interactions, social interactions, learning, agent heterogeneity, and (agent) adaptation. To gain insight in how resilience emerges from these mechanisms simulation models are required that can represent these mechanisms, like Agent-based Models (ABMs). Currently the capabilities for analysing ABMs and exploring their parameter space are limited, due to the complex behaviour of ABMs, the high computational costs, and large number of parameters and variables involved. In addition, ABMs have no closed-form solution and hence no gradient-based methodologies can be used to locate tipping points in parameter space. We propose a methodology for analysing ABMs and locating tipping points that uses support vector machines as surrogate models to represent input-output relations of the ABM. A surrogate model is trained on an initially small set of sampled data from the ABM. It is then used to predict where additional ABM samples should be drawn, and updated using these samples, until it closely matches the ABM output. This iterative sampling procedure generates a surrogate model that for limited computational costs can help in locating tipping points and identifying which parameters in the ABM drive the model towards behavioural regimes. As test-case, we have applied the method to a resource-consumer ABM, with tipping points where the consumer population goes extinct. For this test-case, the surrogate model shows which ABM parameters can drive the system towards extinction.

Operationalizing Urban Resilience: A Machine Learning Approach
Mikhail Sirenko, Scott Cunningham, Yilin Huang, Alexander Verbraeck

The rapid development of urban areas along with uncertainties associated with climate change poses numerous problems for both urban planners and citizens. It is unknown when an extreme climatic effect will strike, what will be its duration and power. The concept of urban resilience perceived to be promising in that regards. However, the practice of it is holding up due to a variety of discrepancies. During the last decade, cities have been accumulating a lot of data that is available now for public use. Advances in engineering boosted machine learning and provided it with a possibility to efficiently analyze complex data sets. To bridge the theory and practice of urban resilience, it is proposed to use open data and machine learning algorithms for its assessment. This study suggests a computational framework based on the concepts of vulnerability and socio-ecological resilience. The framework is a combination of clustering, dimensionality reduction and regression algorithms and it uses open data sets. The case study of this research is July 2019 European heatwave and its impact on citizens of The Hague. It was found that the heatwave had a significant effect on The Hague's population. The number of ambulance calls (proxy for vulnerability) has doubled during the period of the heatwave. It turned out that some regions of The Hague have a high number of vulnerable individuals, but the amount of resilience capacities is relatively low. Consequently, transitioning to resilient "fail-to-safe"; city requires from the Hague more attention into these areas.

Practical Challenges In The Application Of DMDU Methodologies To Climate Risk Assessment And Management (Room A)
Chair: Ad Jeuken, Umit Taner, Casey Brown, Patrick Ray

A systematic exploration of change in the Tuolumne River Watershed

John Kucharski, Wyatt Arnold, Saiful Haque Rahat, Jennifer Olszewski, Romain Maendly

In this lecture we present a process for resolving water resource system vulnerabilities through systematic exploration of the complex linkage between multifaceted climate change, nuanced hydrology, and intricate operational decisions. This is done within the context of a bottom up vulnerability assessment of Tuolumne River Watershed. In our study thermodynamic and dynamic forms of climate change are systemically explored to demonstrate important nuance which is lost when climate change is treated as a lump sum process. In particular, we show that variable climate pathways elicit nuanced changes in the hydrology around which the Tuolumne system's operations are designed. Performance failures driven by hydrologic change are understood within the context of synthetically generated flood and drought events with explicitly identified analogs in history. This process, of linking future hydrologic changes to system performance during flood and drought events with historic relevance, makes the connection between deeply uncertain climate change and water resource planning more clear. It also links climate change to intricate operational decisions thereby producing more effective, better targeted adaptation strategies.

Robust decision making for sustainable development: Classifying, sequencing, and evaluating alternative methodological choices
Enayat A. Moallemi, Fateme Zare, Patrick M. Reed, Sondoss Elsawah, Michael Ryan, Brett A. Bryan

Decision-making in the context of sustainable development aims to inform robust inferences which are effective despite uncertainty. Supporting robust decision-making requires a sequence of interactive methodological choices to be made in setting the problem context, framing the decision problem, evaluating possible solutions, and making recommendations. Methodological choices are influenced by a variety of human factors, originating from cognitive, behavioural, and mental frameworks as well as the beliefs, biases, heuristics, knowledge, and values of stakeholders. In this article, we review the alternative constructs of decision support for sustainable development. We discuss how different ways of performing decision support, which we call decision support paths, emerge from the cumulative effects of individual methodological choices under the influence of human factors that shape how problems are perceived and framed. We argue that methodological choices create a path dependency, generating decision implications which are sensitive and hidden consequences of the path taken in an analysis. We conclude by discussing frontier challenges, emerging future opportunities, and research priorities for improving robust decision making for sustainable development.

Selection of the smallest subset of informative scenarios for the robust optimization of off-grid hybrid energy systems
Federico Giudici, Matteo Giuliani, Andrea Castelletti, Holger R. Maier

Small islands are remote, off-grid communities characterized by an unsustainable water-energy system based on energy intensive desalination technologies to produce potable water and carbon intensive diesel generators to meet a highly variable energy demand. To improve the overall sustainability of small islands, the development of hybrid energy systems, which combine renewable energy sources with power storage technologies, represent a viable and interesting solution. However, the performance of hybrid energy systems over a medium-long term horizon is strongly affected by the deep uncertainty in future climatic conditions (e.g., solar radiation, wind speed). Thus, considering this uncertainty in the identification of the optimal hybrid system design is essential to identify solutions that are robust with respect to a wide range of plausible future scenarios.

Since robustness calculations over the entire scenario space considered are likely to be computationally demanding or even intractable, the aim of this work is to develop an approach that enables the smallest subset of the scenario space to be identified for which the resulting system robustness is similar to that obtained by considering the entire scenario space. This is achieved by adopting an active learning algorithm, as part of which the regions of the scenario space that are most informative are identified in an adaptive manner.

We test our approach on the real case study of the Italian Ustica island. Results show that adaptively selecting the most informative scenarios enables system robustness to be calculated in an accurate manner, while significantly reducing computational requirements.

From risk assessment to adaptation pathways: improvement of Climate Risk Informed Decision Analysis for the Limari basin in Chile

Chris Luger, Ad Jeuken, Koen Verbist, Andrew Warren, Christopher Vivanco, Hector Maureira, Pablo Álvarez

The Climate Risk Informed Decision Analysis (CRIDA) framework incorporates the uncertainties of climate change that impact project planning, socioeconomic justification, and engineering design into a step-wise and collaborative planning process to guide a technical analyst to low-regret risk- and cost-effective solutions;

Research has been carried out to demonstrate and improve, through additional guidelines, the usability of CRIDA, in a pilot for the Limari basin in Chile. The added guidelines (1) offer the analyst numerically based justifications for analytical decisions to ensure a more structured application of CRIDA and (2) improves on co-design aspects by incorporating stakeholder risk perceptions and opinions explicitly in the process.
The Limari Basin has experienced an increase in drought frequency and severity over the last decades. A strategic approach for adaptation is recommended through CRIDA based on an evaluation of the future risk to climate change and the confidence in this analysis and a subsequent systematic assessments of adaptation options. The resulting strategy requires the increase of water supply robustness by adding new water sources that can be implemented in combination with flexible measures for managing demand (i.e. implementing agricultural meshes and improving irrigation efficiency) in parallel or in series to create adaptation pathways.

The study demonstrated the functionality of CRIDA. While the added guidelines required more processing time, subjectivity in the method is reduced thus also reducing possible bias introduced by the analyst. In addition, overall acceptability of the proposed strategies is improved by incorporating stakeholder risk perceptions and opinions explicitly in the process.

Fostering Connections Between Resilience Thinking And DMDU Approaches For Achieving Long-Term Sustainability (Room I-J)

Chair: Benjamin Bryant, Jan Kuiper

Embracing theoretical and methodological pluralism in resilience thinking and DMDU
Wei Liu

Resilience thinking and practice and DMDU are both systematic action research approaches used in highly complex, dynamic and uncertainty contexts, often for addressing wicked problems. While in theory the importance of seeing through multiple theoretical 'lenses' for systematic action research is usually not questioned, in practice methodological and theoretical isolationism often prevail. I argue that to be useful and usable, it is critical for resilience and DMDU researchers and practitioners to embrace theoretical and methodological pluralism: drawing upon more than one theoretical 'lens' and using methods from different paradigms to inform decision making. Contrasting themes, narratives and metaphors embedded in different worldviews and theories offer a rich source of insights and (when made explicit) can shed new light on problematic situations under deep uncertainty. I will critically review examples of how resilience is conceptualized and operationalized in both isolationistic and pluralistic ways and the potential benefit of the latter. I will then discuss possible methodological implications of embracing theoretical pluralism in both resilience thinking and practice and DMDU, as well as how plural, conditional approaches may facilitate more robust decision making and policy advice.

Building bridges: lessons from resilience planning and applied RDM analysis in Pittsburgh, Pennsylvania
Jordan Fischbach

Pittsburgh, Pennsylvania was selected as one of Rockefeller's 100 Resilient Cities in 2015. A mid-sized U.S. city, Pittsburgh has been widely recognized for its recovery from the collapse of the steel industry a generation ago. Looking ahead through the next decade, the city's Office of Sustainability and Resilience has been working to identify investments and policy changes to reduce the city's vulnerability to acute shocks and chronic stresses while meeting ambitious emissions reduction and other goals.

The RAND Corporation has been working with the city of Pittsburgh since 2015 as a 100 Resilient Cities Strategy Partner. In that role, we helped develop Pittsburgh's Preliminary Resilience Assessment and first ever city-wide Resilience Strategy. We have continued to engage with the Mayor's Office and other city decision makers through the development of the city's Equity Indicators, a broad effort to measure the state of equity in the city and work towards a system of continuous measurement for key city goals.

In parallel, we have also been conducting a series of quantitative DMDU projects in Pittsburgh, using a Robust Decision Making approach to help improve local and

regional stormwater management and evaluate emerging large-scale green stormwater infrastructure strategies for watersheds of focus. These efforts have included many of the same decision makers and stakeholders focused on the city's broader resilience goals. In this talk, I will draw from this deep body of work to describe lessons learned working at the confluence of qualitative resilience planning, measurement and assessment, and quantitative DMDU.

Resilience as an analytical uncertainty
Patrick Steinmann, George van Voorn

Humanity is increasingly reliant on complex socio-environmental and -technical systems for critical ecosystem services. Understanding and improving their resilience may be essential to ensuring continued provision of these services in the face of an uncertain future. The term resilience is varyingly defined and operationalised. This ambiguity represents a significant hurdle in model-based decision support, as stakeholders may have unique perceptions of, and metrics for, the supposed resilience of their common system. These metrics will likely give differing quantifications of the system's resilience, but cannot easily be rank-ordered or compared. We see this ambiguity as a form of deep uncertainty, specifically the third element of Lempert, Popper and Bankes' original definition - a lack of stakeholder consensus on how to value the desirability of alternative outcomes.We investigate various methods of addressing this 'analytical uncertainty', drawing from management theory as well as computational optimization approaches, on a complex adaptive system model. We find that some methods are useful for making explicit the trade-offs between different quantifications of resilience. This knowledge is useful for model-based resilience assessment in multi-actor systems, but may also be generalizable to other decision support situations with ambiguous objectives.

Uncertainty and multifunctionality as bridging concepts from socio-ecological resilience to infrastructure finance in water resource decision making
Anita Lazurko

Uncertain climate projections, multiple possible development futures, and a financing gap create challenges for water infrastructure decision making. In contrast to conventional predict-plan-act methods, an emerging decision paradigm based on socio-ecological resilience supports decisions that are appropriate for deep uncertainty and leverage multifunctionality. Concurrently, water infrastructure project finance plays a powerful role in sustainable infrastructure development but remains disconnected from discourse in socio-ecological resilience. At the time of research, a project to transfer water from Lesotho to Botswana through South Africa was at pre-feasibility stage. This case was analysed through documents and interviews to investigate how uncertainty and multifunctionality are conceptualized and considered in decisions for the resilience of water infrastructure. Based on these findings, bridging concepts were explored that might allow project finance to better consider deep uncertainty and enable socio-ecological resilience. Interviewees conceptualised uncertainty as risk, ambiguity and ignorance and multifunctionality as politically-motivated shared benefits. Numerous efforts to adopt emerging decision methods that consider these terms were in use but required compromises to accommodate the persistent, conventional decision paradigm, though a range of future opportunities were identified. Bridging these findings to project finance revealed opportunities to consider a more comprehensive scope of risk, leverage risk mitigation measures, diffuse risks and benefits over space, time and to diverse actor groups, and to clarify roles to achieve multiple objectives for resilience. In addition to insights into how multiple decision paradigms interact in real-world decision contexts, the research highlights untapped potential at the juncture between deep uncertainty, socio-ecological resilience and finance.

Toward Supply chain resilience: consequence-based risk analysis using exploratory modeling
Bahareh Zohoori, Jan Kwakkel, Alexander Verbraeck

Today's complex supply chains sustain their competitive advantages using advanced strategies such as outsourcing, globalization, or just in time (JIT). These advances, however, make supply chains more vulnerable to disruptions. As a result, supply chain resilience is an emerging research topic. One of the main challenges that is being faced is how to cope with the inherent unpredictability of future disruptive events. Some researchers suggest vulnerability analysis of a supply chain in which the consequence of possible disruptions are explored without taking into account the root cause of the disruption, its probability of occurrence, or its severity. In this research, we investigate the contribution that decision making under deep uncertainty methods can make in supporting consequence-based risk analysis of a supply chain. Specifically, this research investigates the potential contributions of exploratory modelling in the context of supply chain risk management which remains

unexplored yet in the current literature. We use a discrete event simulation model of a stylized make-to-order supply chain, and explore its dynamics over a large ensemble of disruption scenarios. These disruption scenarios vary with respect to disruption time, disruption location, disruption duration, post-disruption functionality, and the recovery rate of disrupted element. We analyze the dynamics using scenario discovery, to identify the vulnerable components of the supply chain which are in need of resilience practices. Next, we apply many objective robust decision making (MORDM) to evaluate the efficiency of various pre-disruption and post-disruption actions in the literature on supply chain resilience, in order to identify robust actions.

Embracing Uncertainty In Regional Energy Planning And Management (Room I-J)

Chair: Cornelia Colijn, Mark Alan Hughes, Oscar Serpell

Extending Shared Socioeconomic Pathways: Developing multi-scale internally consistent scenarios for Canada's energy futures

Jude Herijadi Kurniawan, Vanessa Schweizer

The Shared Socioeconomic Pathways (SSPs) is part of the new scenario framework of the Intergovernmental Panel on Climate Change to support more in-depth investigations of the linkages between climate change, economic development, adaptive capacity, and socio-cultural aspects of energy use and technological change. Although scenarios produced for climate impact assessments include empirical and theoretical information from computational models, they also embody qualitative assumptions that cannot be determined scientifically. These assumptions are intended to generalize socioeconomic trends for larger spatial scale analyses. However, many socioeconomic trends are better understood at more localized scales. This situation requires an analytical approach that is multi-scale. Under the Shared Socioeconomic Pathway (SSP) scenario framework, the global socioeconomic developments in the future are categorized into five representative pathways, which will be linked to assess scenario consistency for Canada's energy futures. Such linking can unpack important climate and energy policy questions. Here we applied linked cross-impact balance analysis (linked CIB) (Schweizer and Kurniawan, 2016) to develop multi-scale internally consistent scenarios for Canada's energy futures. The linked CIB can connect scenarios produced independently (by different author teams). Canada's energy scenarios were developed first only to be linked to the global SSP scenario kernels developed by Schweizer and O'Neill in 2014. The results show that, in a decarbonized world, Canada would be most likely decarbonized as well. However, the boundary condition can also be non-restrictive, meaning that Canada can still be decarbonized even though the world is not decarbonized.

Participatory multi-modelling under deep uncertainty for robust energy infrastructure development strategy

Igor Nikolic, Jan Kwakkel, Eefje Cuppen, Jaco Quist

In the Dutch energy infrastructure sector, deterministic capacity planing and single scenario strategy development is the norm. The Windmaster project, performed by the key infrastructure actors in the Rotterdam Port Industrial Complex (RPIC), is the first introduction of DMDU concepts to the Dutch energy infrastructure world. Project applied participatory multi-modelling under deep uncertainty to explore impacts of stakeholder energy infrastructure investment strategies across a vast scenario space impacting energy infrastructure capacity requirements.

The participatory modeling process consisting of visioning, back-casting, system decomposition, model formalization and specification and finally sense making sessions. The multi-model combines social, economic and technical components. It combines socio-economic infrastructure investment decision making by the infrastructure operators, load-flow computation of e current and required future energy transport capacity and a submodel determining technically feasible specific investments required for solving capacity bottlenecks under future demands. scenarios. The technical model cover high and middle voltage electricity grid, natural gas and H2 grids, and contains all major energy consuming and producing assets and all major energy infrastructure elements in the RPIC.

The project delivered a proof of concept robust adaptive energy infrastructure investment plan, and identified several

novel real world investment strategies during the participatory process.

This paper, next to presenting the project, focuses on the methodological aspects involved in the design of the participatory process, using the boundary object, points of passage and translation between social world concept, its role in multi-modelling and and identifies key factors influencing the acceptance of multi-modeling and deep uncertainty concepts.

Using DMDU Methods to Evaluate the Robustness of Costa Rica's National Decarbonization Plan
David Groves, Edmundo Molina, Luis Fernando Victor Gallardo, Guido Godinez Zamora, Jairo Quiros Tortos, Felipe De Leon, Valentina Saavedra Gómez, Adrien Vogt-Schilb

Costa Rica is one of the few developing countries with an absolute and unconditional greenhouse gas (GHG) emissions reduction target. Its Nationally Determined Contribution for the Paris Climate Agreement specifies a long-term commitment to carbon neutrality by 2085. Meeting the associated targets will require Costa Rica to reverse trends in total GHG emissions, with significant reductions from the transportation sector. In February 2019, the President of Costa Rica, Carlos Alvarado, released a National Decarbonization Plan.

This IDB-funded study uses DMDU methods to assess the robustness of Costa Rica's Decarbonization Plan considering a complete assessment of the plan's costs and benefits, using a modeling framework centered around an OSEMOSYS energy model. We will describe how DMDU techniques were used first to assess the costs and benefits of the transportation portion of the decarbonization plan under significant uncertainty about the demand for transportation by modal scheme, the adoption rates and costs trajectories of various technological platforms, the costs of energy and fuels (both traditional and alternative options), and future availability of renewable energy sources. We then describe how a comparison of these results to another set of unconstrained optimized decarbonization schemes helps to better understand how Costa Rica should adapt to future uncertainty. We will conclude by describing how DMDU methods help identify the largest implementation risks to the decarbonization plan and guide its adaptive implementation. We will also discuss on-going efforts to expand this assessment to other non-transportation components of the Plan, including land use, waste management, and buildings and industry.

Ex-post Evaluation of Deep Uncertainty in Infrastructure Design (Room G)
Chair: Marc Neumann

Do we understand performance dependencies, trade-offs, information value, and robustness in dam design and operation?
Federica Bertoni, Andrea Castelletti, Matteo Giuliani, Patrick M Reed

Globally, many countries are actively seeking to maximize the hydropower potential of major river basins, yielding proposals for constructing approximately 3,700 major dams in the near future. At present, economic cost-benefit analyses are the dominant approach for evaluating candidate dam designs. Yet, they fail to explore the interdependence of dam design and operation, while a consideration of alternative reservoir operating schemes may help to avoid biases in how optimal dam sizes are identified. Moreover, the amount of information that is becoming available to water system planners, together with deeply uncertain changes in hydro-climatic variability and human demands motivate the need for robust assessment frameworks that capture the tradeoffs between users, how both dependencies in dam sizing and operations and information influence these tradeoffs, and the ultimate robustness of the infrastructure systems.

This work presents an integrated multi-objective framework to solve coupled dam sizing and operation design problems. The framework combines Multi-Objective Robust Decision Making and Evolutionary Multi-Objective Direct Policy Search into a novel approach to dam sizing, which internalizes the operation design, identifies the most valuable information to inform the system design and explicitly considers uncertainty in external drivers. We demonstrate the potential of this integrated dam design framework through an ex-post design analysis of the Kariba dam in the Zambezi river basin. Results show that the existing Kariba system is critically vulnerable to changing hydro-climatology and human irrigation demands, whereas our framework leads to a significant improvement in the overall system robustness, together with a reduction in capital costs.

Quantifying the feedbacks between flood infrastructure and geomorphological processes in an uncertain deltaic

environment: A case study of the coastal zone of Bangladesh
Amelia Paszkowski, Jim Hall

Over the last century, the world's deltas have increasingly become human-dominated systems, with the Ganges-Brahmaputra-Meghna (GBM) delta being no exception. From the 1960s, embankments were constructed across the coastal zone of Bangladesh, to provide protection against flooding and increase the country's agricultural production. The success of this programme is being disputed, with an increasing number of studies showing that the polders have in fact exacerbated flood risk. Coastal and fluvial geomorphology are greatly under-researched as drivers of risk, typically only assessed as slow long-term processes responding to change. However, this study argues that it is precisely the dynamic interplay between geomorphic processes and anthropogenic actions that have altered and contributed to the increase in flood risk of coastal Bangladeshi communities. Through a deepened understanding of the intricate feedbacks between geomorphology, land management, community vulnerability and flooding, the long-term performance of the polders as flood protection infrastructure in the GBM delta can be more holistically assessed. These feedback systems are examined and quantified using a spatially explicit systems dynamics model, the theoretical framework and concepts of which can be applied to other global mega-deltas with similar dynamics. Under the deep uncertainty of future sea-level rise, storm surge frequency, monsoonal patterns and the geomorphological response to these, this integrated human-nature model will allow the exploration of more sustainable and suitable land and water management schemes for coastal Bangladesh.

How high to elevate a house to manage deeply uncertain flood risks?
Mahkameh Zarekarizi, Klaus Keller

Elevating a house is a common strategy to mitigate flood risks. The United States Federal Emergency Management Agency (FEMA) recommends elevating houses to at least one foot above the Base Flood Elevation (BFE), the water elevation associated with the 100-year flood. This recommendation still leaves open the question whether (and if so by how much) to elevate the houses. This problem is typically addressed in a single objective cost-benefit framework that often neglects key uncertainties. Here we use a multi-objective decision analysis that considers key deep uncertainties. We show how considering uncertainty changes the trade-offs and the acceptable decisions and identify the key drivers of poor outcomes.

The Deep Uncertainties of Legislative Processes (Room A)
Chair: Nidhi Kalra, Steven Popper, Robert Lempert

Can Congress Contemplate Deep Uncertainty?
Nidhi Kalra

After a decade of research in DMDU, I left RAND in 2018 to serve as the senior technology policy adviser to U.S. Senator and presidential nominee Kamala D. Harris. In my year in this position, I asked myself -- what legislative proposals require long range planning amid deep uncertainty? Does legislation or the legislative process recognize the need for such thinking and how is it met? How can legislation be crafted to incorporate ideas of uncertainty, robustness, and adaptation?

In this talk, I will share my observations on these questions, drawn from my year in the legislative trenches and making reference to specific legislation that illustrates these observations. My remarks will not be based on a rigorous analysis of these questions, but on my personal experiences in asking ""How can I use my DMDU and other skills to improve how this country makes policies?""

For illustration, my observations include:
- Members of Congress have little to no access to expertise on identifying and managing deep uncertainty.
- Legislation is itself not amenable to managing uncertainty because it is one of the least flexible policy instruments, and because it is very difficult to write legislation that is itself flexible.
- Adaptation is therefore usually forced in crude ways -- through sunsetting of legislation that therefore must be reauthorized.
- The best entry points for deep uncertainty may be with the Congressional Budget Office and similar bodies which, often with use scenarios or sensitivity analysis, but to date offer no DMDU methods.

The Road to Zero: DMDU Concepts in Support of Legislative Coalition Building
Steven Popper

Legislative processes have become more complex as wider access to information and communications tools multiply

centers of stakeholder opinion. This leads to confusion for legislators and difficulties for advocacy groups in coalescing around consistent positions for legislation and ancillary public and private sphere support activities. Groups may agree on one sought-for goal, but they may widely differ in assumptions regarding appropriate policy, legislative roles, and what other criteria define a satisfactory future. DMDU concepts could play a large role in such settings, but the processes and environment of policy discourse at the stakeholder level rarely lend themselves to analytical modeling – even if appropriate models could be made practical and available.

The Road-to-Zero Coalition of 900+ organizations including industry groups, single-issue advocates, professional organizations, insurers, regional governments, and civil-society groups wishes the U.S. to have zero traffic fatalities by 2050. They agree on little else. Some promote vigorous legislation, others emphasize regulatory change, market signaling, changes in infrastructure design, or technological fixes. They possess widely differing assumptions about the future or, indeed, even what a desirable vision might be. This talk will describe methods used by researchers in direct engagement with the RTZ Coalition across a series of workshops supported by interim analysis. It will describe the framework as well as qualitative methodologies used to bring such a diverse body to a consistent, consensus view on the criteria for evaluating outcomes and the selection among alternatives to define a robust pathway toward achieving their vision.

Can Credible Commitment to Long-Term Policy Goals Be Accomplished?
Detlef Sprinz

Governments can only credibly bind future governments if they can instantaneously do so (Urpelainen, 2011) and even less future electorates or selectorates. Kydland and Prescott (1977) define the challenge of consistent decision-making over time as the challenge that only under conditions of perfectly foreseen circumstances, optimal policies can be pursued over time. Should, however, different policies be optimal at different points in time, the issue of credible commitment arises and optimal policies at an earlier point in time may not coincide with optimal policies at later points in time. The central problem is that optimality at a future point in time cannot influence optimality at a prior point in time. This challenge is exasperated by the degree of depth of time for long-term policies to reach desired goals (Hovi et al., 2009; Sprinz, 2009).

In this paper, I wish to (i) develop a typology of long-term time inconsistency challenges by expanding on Kydland and Prescott (1977) and (ii) map the array of commitment devices or mechanism to the types time inconsistency challenges. Particular attention will be placed on global climate change as one perhaps one of the gravest long-term policy challenges with a 1.5-2°C change in global mean temperature goal.

Posters

A Typology of Problems and Suitable Decision Support Methods for Climate Change Adaptation in Water Management
Umit Taner, Ad Jeuken, Bart van den Hurk, Frederiek Sperna Weiland, Marjolijn Haasnoot
Climate change is already occurring, and challenging water planners through increasing temperatures, rising sea levels, more frequent storms and floods, prolonged droughts, and others. Adaptation can reduce, prevent, or increase resilience to such hazards, and this often requires the use of DMDU methods due to the inherent uncertainties involved with climate change. In many real-world problems, adaptation planners have little guidance on how to select and apply the most appropriate decision approach for their needs. To address this challenge, we first provide a classification of adaptation decision problems with respect to several common features including the decision context (planning purpose and objectives, stakeholder involvement, etc.), geographical scale (project, basin or regional level), time horizon and the preferred level of risk tolerance. We then discuss these features in relation to the commonly applied DMDU methods, including Robust Decision Making,

Decision Scaling, Robust Optimization, and Dynamic Adaptive Policy Pathways.

Adaptation to Urban Heat Waves Under Deep Climate and Socio-Economic Uncertainties
Rui Shi, Robert Lempert, Benjamin Hobbs, Debra Knopman

The growing frequency and severity of urban heat wave events, resulting from the confluence of climate trends and land use changes, pose growing health risks. To mitigate these risks, adaptation within urban areas will be essential. Urban planners seek effective strategies for adapting to these climate impacts, such as land-use modifications (e.g., green infrastructure) and socio-behavioral changes (e.g., public education, cooling centers) to yield the greatest health benefits possible, given scarce public resources. But deep uncertainties concerning future climate, socio-economic conditions, and the effectiveness of alternative strategies, together with long lead times to implementation, mean that near-term decisions will need to be made without fully knowing their consequences. Robust and flexible strategies thus become a central concern for urban heat planning. This study employs robust decision-making to urban heat adaptation, focusing on Baltimore, Maryland. Our study explores a large ensemble of plausible future states of the world including various climate, socio-economic, and demographic conditions, and then evaluates the robustness of alternative strategies. The study defines climate scenarios using multiple climate projections from the NA-CORDEX data archive and uses ratios of present and future heat risk indices, affected by adaptation strategies, as health outcome metrics. A decision-support tool with interactive maps will show the most/least heat-vulnerable places in Baltimore and the effectiveness of alternative strategies across scenarios. As part of the Mid-Atlantic Regional Integrated Sciences and Assessments Team, this project will facilitate dissemination and use of these tools by decision-makers in choosing adaptation strategies within a complex urban-climate system.

Addressing the Complex Relationship between Green Infrastructure and Climate Risk Under Deep Uncertainty
Anita Lazurko, Monica A. Altamirano

Green infrastructure (GI) is comprised of planned networks of natural and semi-natural areas, which deliver ecosystem services and contribute to climate adaptation and mitigation. GI provides greater resilience to gradual change and shocks, but the functionality of GI interacts with social-ecological systems in complex and uncertain ways. The lens of deep uncertainty highlights a dual relationship between climate change and GI. Namely, GI mitigates climate change risks as healthy ecosystems act as buffers to extreme events, but the ecosystems themselves may also be vulnerable to the impacts of climate change. Therefore, as we adopt GI as a key element of climate adaptation strategies, a fundamental question is the ability of different GI types to adapt to a range of climate futures. We investigated the vulnerability of different types of GI to changing conditions and increasing variability driven by climate change, including the effects of climate change on biodiversity, which in turn affects the productivity of ecosystems. We adopted an infrastructure management approach in conceptualizing the vulnerability of GI, which defines vulnerability in terms of loss of functionality for key services provided by GI in a given context. The objective of the research, conducted within the H2020 NAIAD (NAture Insurance value: Assessment and Demonstration) project, is to contribute to uptake of GI for climate resilient water management by 1) investigating existing knowledge about interactions between localized climate hazards, physical vulnerabilities of GI, and risk, and 2) exploring a scientific agenda for improving risk management of GI under deeply uncertain futures.

An investigation into the applicability of Robust Decision Making to complex Strategic Defence decision-making.
Meghan Brady

Dstl constantly strives to improve its internal capability by investigating and trialling analytical methods. This poster details a recent investigation into the applicability of Robust Decision Making (RDM) to strategic Defence decision-making. Throughout our trial we have explored the analytical concept and its existing applications, both quantitative and qualitative, and have improved our understanding of its process.
RDM, and other similar approaches, are often applied to well-understood, quantifiable systems. Formally, they may require large quantities of data and computational power in order to be effective. For many high-level strategic Defence decisions sufficient data, computational models and quantifiable relationships may not be available.
We therefore focused on exploring the types of questions which may benefit from informal, qualitative RDM and the challenges involved in this application of the process. We also investigated how qualitative RDM analysis can add significant value, if at all, relative to other decision making

approaches such as Multi-Criteria and Info-Gap Decision Analysis.
By examining its strengths and limitations, and comparing it to other similar methods, we are now better able to determine the types of questions that may benefit from RDM and the skills and resources required for its successful application.
This poster outlines the journey from investigating an analytical concept to our recommendations for its Defence strategy and policy applications.

Approache to integrate people's representations of climate change within adaptation pathways.
Xénia Philippenko, Gonéri Le Cozannet, Lydie Goeldner-Gianella, Ywenn De La Torre

As climate changes and increasingly affects coastal areas due to erosion and flooding, adaptation pathways are becoming a prominent approach to address deep uncertainties surrounding coastal adaptation. However, social research has shown that people's representations of climate change can either facilitate climate policies or act as a barrier to successful adaptation (e.g., Eisenack et al., 2014; Hinkel 2018). Here, we explore how to integrate people's perception and representations of their territories, of climate change and adaptation within the adaptation pathways framework, and we present a preliminary application in Saint-Pierre and Miquelon, a French oversea territory located south of Newfoundland (Canada) affected by sea-level rise, erosion and flooding. The method starts with social surveys identifying different representations toward climate change and adaptation measures for different climate scenarios, as well as past tipping points that change people's representations. Then, we propose to add a formal step to consider people's representations within state of the art methods to design dynamic adaptive policy pathways (Haasnoot et al., 2013). Finally, people's representations can be considered in subsequent steps, for example as indicators in adaptation pathway maps. We seek to determine how the proposed approach may help anticipating future barriers and opportunities for successful adaptation.

Assessing alternatives under different climate scenario ensembles
Robel Geressu, Christian Siderius, Seshagiri Kolusu, Japhet Kashaigili, Martin Todd, Declan Conway, Julien Harou

Climate model scenarios have different likelihoods and are generated by climate models differing in their predictive skill. Decision-making under uncertainty analyses which make recommendations based on extreme scenarios are controversial. One approach is to use a sub-set of climate model predictions by considering the regional skill of climate models in replicating observed climate characteristics. However, different ranking of climate models could be used, considering various forecasting performance criteria. Generating robust decision alternatives over different climate scenario ensembles leads to large computational requirements for multi-objective robust optimization of large-scale resource system. In this study we suggest an automated, computationally efficient approach for optimizing decision alternatives over different ensembles of climate projections. The search algorithm selects climate scenario subsets based on their relevance to performance objectives, their trade-offs and the possible decision alternatives. Post optimization visualization of decision alternatives over the different uncertainty regions allows considering different degrees of robustness and their trade-offs with cost and other objectives. The proposed approach reveals potential outlier climate scenarios based on decision maker requirements thereby contributing to a relatively efficient and transparent assessment of decision alternatives under climate change.

Combining morphological analysis with morphological distance analysis to identify weak signal scenarios
Bruce Garvey

Weak signals abide in the domain of the uncertain. This paper explores two linked but oft neglected decision support methods, Morphological Analysis (MA) and Morphological Distance (MD), which can identify viable scenarios at the periphery of the analyst's vision and thus offer the opportunity of a technological breakthrough or innovative policy shaping options. MA initially reduces large multi-variable problem spaces to much reduced internally consistent sets of viable scenarios. Using MD as a follow-on, these scenarios are further analysed for divergence from the current state of knowledge to reveal scenarios increasingly at variance with such knowledge, whilst remaining internally consistent. The wider the distance the scenarios are from current knowledge the more likely they are to embrace configurations containing something which has not previously been considered, increasing the probability of a breakthrough. The paper presents two practical examples of how linked MA and MD is used to identify, and isolate scenarios qualifying as weak signals. MD was applied to help identify new options in apartment block design revealing how the method reduced an initial problem space

of some 155k configurations to just 213 viable outlier/weak signal options (a 99.8% reduction), which could then be analysed by architects/structural designers. A second example shows applied the method to enhance PESTLE analysis. Whilst MA is a versatile method of generating thousands of scenarios, the method's widespread adoption has been hindered by the inability to reduce these scenarios to manageable sets and subsequently the degree of divergence between scenarios, which MA/MD now affords.

Dynamic Adaptive Ecosystem Pathways for river deltas
Jos Timmermans, Jan Kwakkel, Peter Herman, Maarten Kleinhans

Climate change will soon render conservation-oriented approaches in ecosystem management obsolete. For river deltas the combined climate and bio-diversity crisis constitute a threat for, ánd offers opportunities for ecosystem development. To guide climate adaptation in river deltas under uncertainty Dynamic Adaptive Policy Pathways are successfully applied. This method holds a promise for mainstreaming ecosystem adaptation in climate adaptation policy.
The first scientific challenge in applying this approach to ecosystems in river deltas, is to develop fast but reliable models that grasp future bio-geo-morphological adaptations of aquatic delta ecosystems to climate change and socio-technical interventions. The model needs to be able to simulate ecosystem development over a long time horizon (100+ years) and produce 100.000 to 500.000 runs in a workable duration. Developing such a fit for purpose integrated estuarine ecosystem model is a scientific breakthrough in itself, as it requires morphologists and ecologists to condense their combined detailed knowledge and system understanding into a limited set of relevant processes.
In addition, model based development of policy pathways often entails simplifying the policy problem to curb methodological and computational challenges. Delta ecosystems functioning however depends on numerous parameters and boundary conditions and requires dealing with multi-stakeholder trade-offs. The second scientific challenge addresses the methodological and computational issues in ecosystem pathway development under uncertainty. Mainstreaming Dynamic Adaptive Ecosystem Pathways into the climate adaptation debate is the societal challenge of the project proposed.

Engaging Disperse Stakeholders
Maria Teresa Piacesi

Using interviews and questionnaires, this study proposes an approach to engage a disperse group of stakeholders in the structuring of the deep uncertainty situation on how to prepare engineering students to face the present and future challenges in aeronautics. In Phase 1, stakeholders selected through the Power/Interest Grid are guided to answer about their perception of the situation, past successes and failures, present and future needs, potential future drivers. The initial responses are analyzed and organized to construct the scenarios. In Phase 2, the stakeholders are presented to the described scenarios and suggest actions/solutions that are organized and summed-up. The analysis is framed in Phase 1 and explored in Phase 2, with discussion of some trade-offs. Although some decisions are suggested, the final decisions and policy are left for the reader.

Evaluating Jordan's water security under uncertain future conditions using a multi-agent hydroeconomic model
Jim Yoon, Christian Klassert, Steven Gorelick, Philip Selby, Thibaut Lachaut, Stephen Knox, Nicolas Avisse, Deepthi Rajsekhar, Amaury Tilmant, Bernd Klauer, Julien Harou, Daanish Mustafa, Katja Sigel, Erik Gawel, Josue Medellin-Azuara

Our work focuses on evaluation of long term water security in Jordan using a multi-agent, hydroeconomic model of the country's water system. Jordan ranks among the most water-scarce countries in the world, a situation exacerbated due to an influx of refugees escaping the civil war in neighboring Syria. The modular, multi-agent model is used to explore the evolution of Jordan's water system under a range of uncertain future conditions, integrating biophysical modules that simulate natural and engineered phenomena with human modules that represent behavior at multiple levels of decision making. For the multi-agent model, we explicitly account for human agency at multiple levels of decision making, with agents representing riparian, management, supplier, and water user groups. The model is run through the end of the 21st century to evaluate potential supply, demand, and institutional interventions over a wide range of plausible climate and socioeconomic scenarios, developed by downscaling RCP and SSP projections to the Jordan national level. Model results paint an alarming outlook on Jordan's water security, with over 50 percent of the country's household population experiencing critical insecurity by the end of the century over most future model narratives explored. A significant increase in water use disparity is also observed, evaluated by applying a Gini

coefficient of water use to the modeled agent population. Sensitivity analyses are further conducted revealing the hydrologic and human aspects and uncertainties that most strongly influence water security outcomes.

Exploring alternative moral principles for the 'efficiency versus equity' trade-offs in model-based policy analysis
Bramka Arga Jafino, Jan Kwakkel, Marjolijn Haasnoot

When evaluating alternative policies, one often compares the resulting overall economic efficiency with the fairness of the resulting distributional impacts for different stakeholders. The Gini coefficient is the most widely used metrics to evaluate the fairness of alternative policies. The moral principle underpinning the Gini coefficient is egalitarian, aiming to promote equality for all. The moral principle underpinning the economic efficiency aspect is utilitarian, aiming to maximize the aggregate utility of a society. Despite the existence of other moral principles, most model-based policy analysis studies constrain and frame complex policy problems only to trade-offs between efficiency (Utilitarian) and equity (Egalitarian).

In this study, we explore the implications of using other moral principles in model-based adaptation planning for the rice farming sector in the upper Vietnam Mekong Delta. A coupled land-use change and biophysical model was developed to test the efficiency and fairness of several pre-specified adaptation measures. Since the upper Mekong Delta is the main rice production hub of Vietnam, we use the total rice production as an indicator for efficiency. For fairness, we use multiple different moral principles. Specifically, we operationalize, among others, Sufficientarianism, Prioritarianism, Weighted Utilitarianism, and the Rawlsian difference principle, to assess the distributional impacts of adaptation measures on the welfare of rice farmers. We observe how the ranking of the measures changes when different moral principles are used, and how these rankings are influenced by climatic and socioeconomic uncertainties.

Future dynamics of development, climate impacts and water resources adaptation in Malawi
Ajay Bhave, Suraje Dessai, Declan Conway

Outflows from Lake Malawi sustain hydropower, irrigation, urban water supply and flow requirements for a Ramsar wetland in Malawi. In the early 20th century, lake levels dropped below the outflow threshold, leading to no outflows. The transboundary Lake Malawi Shire River Basin is immensely important to Malawi's development, and changing risks could affect water, food and energy security. We co-developed a Water Evaluation And Planning (WEAP) model with stakeholders that incorporates their experience and priorities; for e.g. operation of the outflow regulating barrage. We forced the model with 29 bias-corrected CMIP5 model-based projections available through the Future Climate For Africa programme, and socio-economic development pathway elicited by stakeholders. We stress-test existing and proposed infrastructure against these scenarios, and assess robustness of water management options. Future climate change simulations (2021-2050) demonstrate deep uncertainty in precipitation-led runoff response and lake levels. Extremely high lake levels could result in downstream floods, lake levels within the range of recent observations could constrain downstream flows, and low lake levels could include instances of Lake Malawi levels dropping below the threshold. Lake levels are impacted by withdrawals from the Lake Malawi catchments for irrigation and urban water supply, which affects the risk profile (compared to the baseline risk profile) of hydropower infrastructure downstream of the Kamuzu barrage. Dynamic management of barrage operation shows better ability to address risks, but limited robustness against uncertain future precipitation. Such risk and robustness assessments using a model co-developed and shared with stakeholders could usefully inform decision making in Malawi.

Identifying uncertainty by mapping epistemic discourse
Alexander Wanitschke, Simon Hoffmann

The concept of uncertainty has been receiving increasing attention in various sciences. While many theories and methods about operationalization of uncerainty have been successfully applied, little has been published on how to identify und substantiate uncertainties about a problem. We feel this is a very problematic void in uncertainty analysis because it can unconsciously lead to cherry-picking uncertainties and disregard of certain unquantifiable or undetectable decision-relevant information. While the categorization and communication of uncertainties can help strengthen the evidence and increase credibility, missing substance and justification of the apparent uncertainties can jeopardize the analyst's endeavor. In this paper we present a multi-disciplinary approach - called argument mapping - for scientists and decision makers to generate and justify a list of uncertainties they later want to process. We claim that it can assist in substantiating claims about what is known and what is uncertain before beginning to classify and process uncertainties.

Investigating the role of foresight in policy development and risk management in Pacific Island Countries
Daniel Lund

National policy development and decision-making has become increasingly influenced and impacted by global trends, markets, politics, and environmental shifts. Pacific island countries are under major pressure to pre-empt and respond to the interrelated and non-linear environmental, social, political, and economic risks posed by anthropogenic climate change alongside existing development challenges and mounting geo-political tensions. Qualitative analysis has been used to explore the way in which multi-scale and multi-dimensional risks have impacted upon development effectiveness in the Pacific and seeks to understand the degree to which future foresight can be used to articulate and support the political and developmental ambitions of the region. Through semi-structured expert interviews and the observation and participation in a number of key regional climate change related consultations and conferences, the rationale to increase the use of foresight and scenario-based tools to inform regional policy and planning was investigated. Expert opinion suggests that risk management policy and practical implementation of development projects in the Pacific has lacked the foresight required to be effective at scale.
Analysis finds that the complexity and scale of future risks and risk cascades are often under-considered, poorly communicated, or under-estimated in many cases within national plans and development approaches in the Pacific. Foresight deficits have also been exacerbated by external influences. Findings suggest that the success of emerging regional narratives, national efforts to strategically pre-empt change and trigger proactive preparation in anticipation of increasingly intertwined challenges and risks, are increasingly dependent on an integrated understanding of multi-scale risks, opportunities and trade-offs.

Machine learning to support decision-making in scenario-based multiobjective optimization under deep uncertainty
Babooshka Shavazipour, Kaisa Miettinen

In many real-world decision-making problems, different decision-makers are involved with typically conflicting objectives to be considered simultaneously. There is no single optimal solution in these problems because of the conflicting objectives. Instead, several so-called Pareto optimal solutions with different tradeoffs are available. Moreover, the presence of uncertainty (especially deep uncertainty) brings more complexity to the decision-making process. Therefore, the role of the decision-makers is even bolder. Scenario-based multiobjective optimization (SBMOO) can deal with deep uncertainty. However, using scenarios introduces an additional dimension, which brings more complexity. In most cases, for finding a preferred Pareto optimal solution, (s)he needs to provide preference information such as aspiration levels for each objective function. In SBMOO, we have a multiobjective optimization problem in each scenario and, thus, the elicitation of required preference information from the decision maker for all objectives in all scenarios can be very laborious or beyond human capabilities. In practice, we may need to settle for with incomplete preferences. It is not straightforward to apply the existing approaches, developed for incomplete preference handling, to a high-dimensional problem such as SBMOO. In this research, we propose a method for treating the un-known preferences in SBMOO problems. The main idea is to simulate the decision maker's unknown preferences through utilizing machine learning tools in which the available preferences of the decision maker are used for initial training. In other words, machine learning tools are used to learn the relationship between the ideal and/or nadir points and the decision maker's preferences.

Multimethodology for transparent development of representative sets of long-term scenarios
E. Anders Eriksson

This presentation reflects methodological experience from a scenario exercise performed 2018 in the Mistra Geopolitics programme, intended to inform Swedish actors on future developments at the crossroads of geopolitics, international development, and climate change. The nature of the problem area indicated a long-term perspective; 2050 was chose for time horizon. To properly address various aspects, a multimethodology approach was developed based on intuitive logics (IL) and cross impact balance (CIB). We explicitly distinguished between diachronic scenario components – paths from now to the time horizon – and synchronic ones representing 'thick presents' starting at the time horizon and typically thought to prevail for one or several decades thereafter. The key feature of synchronic components is that they support reciprocal or, more generally, circular causalities. Looking for such virtuous or vicious circles turned out a powerful heuristic for discovering the possibility of future societies reflecting radically novel and highly distinctive structural patterns.

Practically, the synchronic work employed a novel graphical development of CIB where – implanting an exploratory spirit more typical of IL – influence coefficients were allowed to vary across scenarios, thus capturing the individuality of each, likely to have emerged during a thirty-year evolution. Starting with a first generation of synchronic end-states, pathways (represented by IL story-maps) and end-states were then co-developed to achieve plausible and consistent total scenarios. The use of model-based scenario representation throughout enables systematic and transparent approaches to ensuring representativity of scenario sets, to facilitating non-participants' auditing of scenarios, and to interfacing with quantitative models.

Participatory governance of energy transition in Jordan: a way to address existing uncertainties in decision-making processes

Love Ekenberg, Nadejda Komendantova, Joanne Linnerooth-Bayer

Energy transition towards a more significant share of domestically generated resources will inevitably lead to a societal transformation, which will affect the interests of existing and emerging electricity generation industries and other stakeholders. To be sustainable, such transition should also address issues of environmental protection and contribution to socio-economic development. A reasonable assumption is that human factors play an important role in energy transition. These human factors include perceptions of different risks connected with technological deployment, as well as views about benefits and impacts generated by different technologies. We present a multi-stakeholder multi-criteria approach to assess the relevance of the Jordan's electricity generation technologies against a set of criteria under uncertainty, which reflect environmental, social and economic components of sustainable development. The results show that the discourse in the Jordanian society is currently dominated by economic rationality, such as electricity costs, supported by concerns about safety during operation and maintenance of electricity generation power plants. The results also show the strong desire of all stakeholder groups to have an opportunity to engage in decision-making processes on energy transition rather than purely to compensate local communities for the installation of electricity generation and transmission technologies.

Preparing for Uncertainties in the Long-Term Transition of a Defense Program

Jake McKeon

U.S. defense strategy relies upon a nuclear triad to credibly and effectively deter global actors from using strategic nuclear weapons. The U.S. Air Force (USAF) manages the land-based Intercontinental Ballistic Missile (ICBM) leg, which includes 400 Minuteman III missiles deployed in silos as well as supporting critical infrastructure. Current U.S. defense strategy supports the acquisition of a modernized ICBM to replace the Minuteman III system and continue providing nuclear deterrence for decades to come.
The USAF ICBM acquisition organization is planning for the transition period, in which the ICBM force will be comprised of both the old Minuteman III and the new ICBM replacement. This transition period may last for an extended period of time, which concludes when the ICBM force is fully transitioned to the new ICBM replacement (e.g. only new missiles in silos). For this transition period, there may be sources of deep uncertainty that can render the ICBM force less effective in their nuclear deterrence posture. Deep uncertainties include, but are not limited to, domestic politics, the regional, national, and global economy, weather, international relations, etc. A transition plan geared toward robustness and resilience will ensure that uncertainties are identified, characterized, and addressed early on.
The author will discuss the current approach and progress of using ABP and RDM methodologies to support this defense organization.

Prioritization of water investments in a changing and uncertain world: the experience of the Chancay-Lambayeque basin in Peru.

Homero Paltan, Diego Rodriguez, Umit Taner, Sergio Contreras, Luis E. Garcia, Alfredo Hijar, Johannes Hunink, Pedro Guerrero

Achieving water security and guaranteeing the sustainable use of water resources require series of investments at the catchment scale. Yet, competing water uses pose an initial layer of complexity about the type of intervention a catchment requires. Additionally, the nature of climatic and no-climatic uncertainties, threating possible investments, leave decision makers with insufficient knowledge about the performance of chosen intervention options in a changing world. So, decision makers require novel tools which would facilitate the description and communication of key metrics in an uncertain future.
This presentation discusses the study of the multipurpose Chancay-Lambayeque Basin water resources hydraulic system (Peru) to changes in climatic and no-climatic

conditions. A series of proposed interventions to enhance the current hydraulic system look to satisfy water supply to ~400,000 people, guarantee water for increasing irrigation activities, and maintain ecological flows, while providing protection for El Niño-driven floods.
The assessment was carried out using the DMDU deiven Decision Tree Framework (DTF, Ray and Brown,2015). This is a bottom-up approach which, in this application, examined the performance of economic, resilience, robustness, and reliability metrics of selected interventions such as the construction of new reservoirs, use of groundwater, and green-infrastructure, subjected to various climate realizations. Also, the effects of changes in urban water supply and irrigation demands, siltation in existing reservoirs, and other non-climatic parameters and trade-offs were analyzed. The results of this study highlight the potential (while acknowledging limitations) of DMDU tools to prioritize investments in river catchment planning while engaging local stakeholders in decision making.

Supporting robust decision-making in Natural Hazard Risk Management through enhanced uncertainty analysis
Emily Harvey, Nicola Smith, Mary Jo Vergara, Yasir Syed, Rob Buxton, Charlotte Brown

Recent experiences with multiple and significant hazard events in NZ over the past decade have led to an increased focus on strengthening disaster risk reduction planning. In a recent project our multi-agency team (GNS Science, M.E Research and Resilient Organisations) combined and extended existing state-of-the-art simulation modelling tools (RiskScape, Post Disaster Cities, and MERIT) to quantify the direct and indirect (flow-on) impacts of a large earthquake in New Zealand's capital city, Wellington. Specifically, we calculated the geomorphic hazard, the physical impact on built/human capital, then translated these impacts into infrastructure disruptions and disruptions to people/businesses, and ultimately, fed these disruptions into dynamic socio-economic modelling to produce estimates of the socio-economic implications for society.

In this work we extend the earlier Wellington earthquake impact modelling by quantifying some of the uncertainty associated with natural hazard event impacts, using three different methods for propagating uncertainty through the existing modelling workflow. In addition to quantifying output uncertainties, we use global sensitivity analysis methods to identify key drivers of model results and important input parameters. In this presentation we will summarise our findings from the project, including an assessment of the practicality of applying the different methods for propagating uncertainty, and their usefulness in supporting the decision-making process.

Surprise doesn't have to be lethal: robust approaches to long-term Defence planning.
Sean Monaghan

According to the strategist Colin S. Gray, coping with uncertainty is "the central unavoidable challenge to defence planning". This poster details a recent investigation by the UK Defence Science and Technology Laboratory (Dstl) into the applicability of robust approaches to long-term planning to help Defence cope with uncertainty.

Robust approaches optimise decisions and strategies to cope with surprise – a consequence of uncertainty. Yet the application of 'robustness' to national security and defence is relatively under-conceptualised. To address this gap in understanding we comparatively assess a range of quantitative and qualitative approaches – including 'min-max', 'info gap' decision theory, Robust Decision Making and Dynamic Adaptive Policy Pathways – focusing on the practical benefits and limitations of applying each approach.

We find that robust approaches can help Defence planners deal with uncertainty in two main ways: by reducing the 'cost of surprise'; and by guiding users through a re-orientated strategy development process that also improves their intuitive understanding of the problem space. In practical terms, robust approaches include a range of techniques from 'light touch' to resource-intensive. However, getting the best out of them places specific demands on practitioner skill and organisational culture.

The application of 'robustness' to the Defence strategy and national security is immature. But their potential justifies further investigation, for as Colin S. Gray has also said, "surprise is unavoidable…But there is no reason why surprise has to be lethal in its consequences".

The Inherent Costs and Uncertainties of Water Scarcity in a Changing World
Flannery Dolan, Jonathan Lamontagne, Robert Link, Mohamad Hejazi, Patrick Reed, Jae Edmonds

Climate and development driven water scarcity poses a major risk to global economic growth and stability, as regional drought impacts propagate through the global

economic system. Past work in this area has largely focused on physical water scarcity rather than its economic impacts. Additionally, previous studies have analyzed local scarcity while ignoring the global context and assumed no or limited adaptive capacity. This work uses the Global Change Assessment Model (GCAM) to capture the effects of market adaptation to physical water constraints across a wide range of potential futures sampled from various earth system models, the Shared Socioeconomic Pathways, varying levels of climate mitigation, and water infrastructure development. Though water scarcity has negative impacts at a global level across all futures, clear regional winners and losers emerge as water-rich basins become virtual water exporters. Scenario discovery reveals that different uncertain factors define meaningful scenarios in different basins, illustrating the need to tailor regional planning scenarios to the basin level while also considering the global context. It is shown that the economic system either amplifies or dampens water supply uncertainty depending on future conditions. The economic uncertainty due to uncertain water supply exceeds 30% of GDP in some basins, representing an economic tipping point where negative impacts persist till the end of the century. This analysis provides insight into what worlds and basins are most prone to these tipping points due to global change.

The Prison Dilemma, Decision-making Framework in the Upper Blue Nile River Basins, Ethiopia
Abay Yimere

The Upper Nile River Basin has varied precipitation and runoff stories. Most of the research suggested that runoff and precipitation would likely to increase in the Sub-Saharan African Countries and particularly in Ethiopia (Andrew Challinor, 2009, Andres Levermann, 2009, Richard Betts, 2009, Polly Ericksen, 2009, IPCC, 2007a). In another note, Elshamy and Sayed described that the likelihood of precipitation in Ethiopia is highly uncertain (2000, 2004). The temperature increase, in general, could increase evapotranspiration and the impact of this on the water availability in the basin is also unclear (Strzepek et al., 2001). And yet, researches on the socio-economic aspects of the upper Blue River basin are scanty and hard to find except some researches done by ENTRO and government reports (ENTRO, 2006).

The Upper Blue Nile, which originates from Ethiopia, contributes over 80% of the Nile waters. Water is also needed in Ethiopia to agriculture, energy, and drinks. Ethiopia's economy depends on rain feed agriculture and about 65% of the population lives without electricity. The available irrigable land in the Upper Blue Nile River basin exceeds 1, 000,000 ha, however; the irrigated land is less than 50, 000 ha. There is no mechanism or frameworks that settle conflicting and demanding priorities. In light off this, a robust decision support tool is essential to minimize, operate and reduce the uncertainties surrounding the Blue Nile River basin.

To dam or not to dam? A microeconomic modeling ensemble to inform robust adaptations to water scarcity in the Órbigo Catchment, Spain
C. Dionisio Pérez-Blanco, Laura Gil-García

Deploying water works in mature water economies inevitably entails a reallocation of benefits from local riparian users (e.g. environment) to new groups of beneficiaries at a regional or national level (e.g. irrigators) that needs to be properly assessed and balanced. The Douro River Basin Authority (DRBA) will decide in the next months whether to build two additional dams in the Órbigo Catchment in NW Spain to expand irrigation water supply and reliability, coupled with a pricing instrument for cost recovery purposes. After receiving a positive environmental assessment from the Spanish Ministry of Environment, the decision on whether to build the two dams is conditional on the assessment of the economic impacts and feasibility of dam construction. This paper adopts a sophisticated yet easy-to-understand exploratory modeling approach that uses computational simulations arising from a Positive Multi-Attribute Utility Programming (PMAUP) microeconomic modeling ensemble to sample uncertainty. This modeling approach is combined with experts' knowledge and opinion articulated through a robust decision-making process. The result is a database representing multiple plausible futures, which is used to identify vulnerabilities of proposed adaptations and potential tradeoffs between responses. Results show that the statu quo strategy where no dam is built is strictly preferred over the dam construction strategy.

Urban green infrastructure to leverage climate resilient investments: a comparison of two CRIDA cases: Udon Thani (Thailand) and Guayaquil (Ecuador)
Guillermo Mendoza, Ad Jeuken, Ignacio Ortinez

Urban resilience to the combination of extreme weather and other socio-economic stressors are increasingly important to global security. The issue of urban resilience is especially relevant given that new estimates from the European

Commission suggest that 84% of the World's population currently lives in urban areas. Moreover, urban growth is expected to continue with the following trends: (i) The physical extents of urban areas are expanding faster than urban populations; (ii) urban areas modify local and regional climates; (iii) ecosystem services are impacted, such as runoff mitigation; (iv) areas of high coastal and riparian biodiversity will be disproportionately impacted; and (v) most of the urban expansion will occur in areas of limited economic development and institutional capacity for resilience. Climate change and socio-economic change will exacerbate the impact of these trends.

Green infrastructure are multipurpose solutions that provide a realistic option for investments that help justify more robust or adaptable solutions. In addition to a water management purpose they can provide additional benefits in aesthetics and growth real estate value, recreation, and environment. However, there is fewer engineering guiding standards, differences in O&M, and more difficult to apply traditional governmental procurement process. This means that quantitative analysis methods need to be improved. We provide two case studies for the implementation of a bottom-up process to plan for urban resilience to floods and droughts using green infrastructure in Guayaquil, Ecuador and Udon Thani, Thailand. We illustrate how green infrastructure is justified for robust and adaptable solutions under deep uncertain.

Value-based Trade-offs in Adaptive Strategies Based on Perceived Uncertainty in Epidemics Response
Emma den Brok, Tina Comes, Jan Kwakkel

During epidemics, decision-makers need to decide where to locate treatment centres and send resources in a constantly evolving and highly uncertain environment. These decisions have value-based implications concerning effectiveness, efficiency, and fair distribution of capacity. At the same time, placement decisions also influence the uncertainty space: by sending resources or positioning treatment centres in a specific region, information about the local situation becomes available and uncertainty is reduced. As such, decision-makers face a trade-off between strategies that aim at reducing uncertainty (exploring) vs. meeting known demand (exploiting).

We used MORDM to analyse the performance of exploring and exploiting strategies. Our results show that explorative policies prevent worst-case scenarios and perform better in terms of equity, but never attain the optimal performance on efficiency and effectiveness of exploitative policies because resources are not fully spent on affected populations. In our presentation, we will discuss the value-based questions and implications that result from this trade-off, considering risk, responsibility and the humanitarian imperative.

Post-conference workshop

Symposium: The governmental challenge of anticipating the future with decisions about end-of-lifetime water infrastructure

Venue: Bouwcampus, Building 26 Part A of TU Delft. Room: Yellow Brick (20 persons)
Date: 8th of November 2019
Time: 8.30 – 13.00

Abstract
Climate change, digital transformation, and the energy transition are among the grand challenges that increase the need for governments to take into account, anticipate, and shape the long term with their current-day investment decisions. Furthermore, in the Netherlands, United States, and other countries water infrastructure is ageing and in need for replacement. This workshop will specifically zoom in on the challenge of anticipating future challenges with decisions about end-of-lifetime water infrastructure. Research findings about this topic will be shared at the beginning of the session. The workshop will include three presentations from practitioners from the Dutch national water authority, a regional water authority, and the Dutch foundation for urban drainage. These presentations will zoom in into three different long-term challenges: of the energy transition, of climate change adaptation at the local level, and of the challenge of ageing/end-of-lifetime water infrastructure. The group will then break out in three to discuss the challenges in more detail and formulate recommendations for practice. We invite both practitioners and academics, from the Netherlands ánd abroad. You can join this workshop together with signing up for the DMDU annual conference, but also by signing up only for this particular post-conference workshop.

Attendees

Abay Yimere, Addis Ababa University
Ad Jeuken, Deltares
Alexa Bruce, University of Massachusetts Amherst
Alexander Wanitschke, Reiner Lemoine Institut
Alexandra Toimil, "IHCantabria" Universidad de Cantabria
Amelie Paszkowski, University of Oxford
Anders Eriksson, Stockholm Environment Institute (consultant; private adress below)
Andrea Castelletti, Politecnico di Milano
Antonia Hadjimichael, Cornell University
Art Dewulf, Wageningen University
Attila Lazar, University of Southampton
Babooshka Shavazipour, University of Jyväskylä
Bahareh Zohoori, TUDelft
Bart van den Hurk, Deltares
Benjamin Bryant, Woods Institute for the Environment, Stanford University
Bramka Arga Jafino, TU Delft
Brian Carter, The Aerospace Corporation
Bruce Garvey, Strategy Foresight Ltd
Carlos Dionisio Pérez-Blanco, Universidad de Salamanca
Casey Helgeson, Penn State
Celian Colon, International Institute for Applied Systems Analysis (IIASA)
Charles Rougé, University of Sheffield
Christian Els, Independent Consultant
Christopher Dacey, Hydroture
Daikichi Ogawada, NIPPON KOEI Co., Ltd.
Dana Stuparu, Deltares
David Behar, San Francisco Public Utilities Commission
David Gold, Cornell University
David Groves, RAND
Detlef Sprinz, PIK - Potsdam Institute for Climate Impact Research
Dewi Le Bars, KNMI
Dominique Chu, University of Kent
Elco Koks, Vrije Universiteit Amsterdam
Elia Alessandro Morciano, estudioOCA
Emiel van Druten, Witteveen+Bos
Emily Harvey, M.E Research
Emma den Brok, Delft University of Technology
Enayat A. Moallemi, Deakin University
Federica Bertoni, Politecnico di Milano
Federico Giudici, Politecnico di Milano
Flannery Dolan, Tufts University
Floortje d'Hont, TU Delft
Francis Andem, University of Uyo, Nigeria.
Frans Klijn, Deltares and Delft University of Technology
Geoff Darch, Anglian Water
George de Gooijer, Independent
George DeMartino, University of Denver
Gideon Gal, Israel Oceanographic and Limnological Research
Gonéri Le Cozannet, BRGM
Guus Luijben, Radboud UMC/RIVM
Guus ten Broeke, Wageningen University
Hanne van den Berg, Harvard University
Homero Paltán, World Bank
Igor Nikolic, TU Delft
Jaap kwadijk, DELTARES
Jake McKeon, RAND Corporation
James Maltby, Dstl (MOD UK)
Jan Kuiper, Stockholm Resilience Centre, Stockholm University
Jan Kwakkel, Delft University of Technology
Janneke Grutters, Radboudumc Institute for Health Sciences
Jasper Verschuur, University of Oxford
Jeremy Rohmer, BRGM
Jim Yoon, Pacific Northwest National Laboratory
John Kucharski, US Army Corps of Engineers
Jonathan Lamontagne, Tufts University
Jordan Fischbach, RAND Corporation
Jos Timmermans, TU Delft
Judith Blaauw, Deltares
Judith Verstegen, University of Münster
Judy Lawrence, New Zealand Climate Change Research Institute
Julie Rozenberg, World Bank
Julien Harou, Univ. Manchester
Karen Meijer, Deltares
Katy Roelich, University of Leeds
Kees van Ginkel, Deltares, VU University Amsterdam
Klaus Keller, Penn State
Kostas Konstantinidis, ESA Advanced Concepts Team
Lake Singh, Aerospace Corporation
Lena Reimann, Kiel University
Leon Hermans, TU Delft
Liese Coulter, University of Leeds
Maike Bennema, Deltares

Marc Neumann, BC3 - Basque Centre for Climate Change
Maria Teresa Piacesi, ITA - Instituto Tecnológico de Aeronáutica
Marianne Schuerhoff, NL Commission for Environmental Assessment
Marina Baldissera Pacchetti, University of Leeds
Marjolijn Haasnoot, Deltares, Utrecht University
Mark Workman, Imperial College London
Marnix van der Vat, Deltares
Matías Paredes, University of Chile
Meghan Brady, DSTL
Melvin Lippe, Thuenen Inst. International Forestry and Forest Economics
Michael Green, Wood
Mikhail Sirenko, TU Delft
Mirre Scholte, Radboudumc
Monica A. Altamirano, Deltares
Muhammad Kashif Nadeem, IOM
Muriel Bonjean Stanton, Sustainability Research Institute, University of Leeds
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Rob Solly, Dstl
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Rory Heard, UK Defence Science and Technology Laboratory
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Samuel Hilton, All-Party Parliamentary Group on Future Generations. (Also Research Affiliate at the Center for the Study of Existential Risk at the University of Cambridge)
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Wouter Kolk, PhD Student at Nyenrode Business University and TU Delft
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