



OVERSHOOT CONFERENCE 2025 | Laxenburg

30. Sept. – 02. Okt.

Book of Abstracts



International Institute for
Applied Systems Analysis



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Program

30th Sep 2025

10:00 - 11:30am	Registration and coffee reception		
11:30am - 1:00pm	Welcome notes Location: Theater Room Welcome note by Prof John Schellnhuber, Director General, IIASA Address by the Hon. Min. Ralph Regenvanu, Minister for Climate Change Adaptation, Energy, Environment, Meteorology, Geo-Hazards and Disaster Management Keynote by Prof Jim Skea, Chair of IPCC Keynote by Dr. Mirey Atallah, Chief of the Adaptation and Resilience Branch, Climate Change Division UNEP Introducing the Overshoot Conference Prof Carl Schleussner, Research Group Lead and conference organiser, IIASA Conference Logistics, Ms Inga Menke, IIASA Moderation: Ms Inga Menke, IIASA		
1:00 - 2:00pm	Lunch Location: Oval Room		
2:00 - 3:30pm	Theme 1: Highest possible mitigation ambition under overshoot Location: Theater Room Annika Högner, Jarmo Kikstra, Joeri Rogelj Theme: 1 Highest possible mitigation ambition under overshoot 2:00 - 2:12pm Introduction 2:12 - 2:24pm How just can we be? Increased European ambition across sectors is required to achieve a fair share of atmospheric space and limit overshoots Jacob Mannhardt, Leo Behmel, Giovanni Sansavini 2:24 - 2:36pm Energy-material dynamics define highest-ambition pathways Harald Desing 2:36 - 2:48pm Multi-dimensional mitigation milestones for peak warming outcomes Lila Warszawski, Malte Meinshausen, Johan Rockström 2:48 - 3:00pm The institutional and socio-cultural feasibility of entering net-negative	Theme 3: Earth System responses up to net zero and beyond Location: Marshall Room 1 Deliang Chen, Biqing Zhu Theme: 3 Earth System responses up to net zero and beyond 2:00 - 2:05pm Introduction 2:05 - 2:23pm Long term overshoot and (ir)reversibility in two emissions-driven Earth System Models Chris Smith, Lennart Ramme, Ada Gjermundsen, Hongmei Li, Christopher Wells, Adakudlu Muralidhar, Timothée Bourgeois, Jörg Schwinger, Chao Li, Cecilie Mauritzen 2:23 - 2:41pm Hysteresis and reversibility of agroecological droughts in response to carbon dioxide removal Laibao Liu, Mathias Hauser, Michael Windisch, Sonia Seneviratne 2:41 - 2:59pm Long(er) term changes in the climate and carbon cycle following a temperature overshoot Tilo Ziehn, Andrew King, Liam Cassidy, Alex Norton, Matt Chamberlain, Pearse Buchanan	Theme 5: Overshoot legacy and tipping elements Location: Marshall Room 2 Jonathan Donges, Caroline Zimm Theme: 5 Overshoot legacy and tipping elements 2:00 - 2:10pm Introduction 2:10 - 2:25pm Impacts of Temperature Overshoots on Climate Tipping Risks Nico Wunderling 2:25 - 2:40pm Mapping the current state of knowledge on overshoot: Uncovering trends and patterns in the scientific literature through a bibliometric analysis. Joshua Fisher, Alexandra Xochitl Gonzalez Edgar, Dorothy Janick, Andrew Kruczkiewicz, Carissa O'Donnell 2:40 - 2:55pm Southern Ocean deep convection in a cooling world - a tipping element? Ivy Frenger, Svenja Frey, Andreas Oschlies, Julia Getzlaff, Torge Martin, Wolfgang Koeve 2:55 - 3:10pm Non-linear permafrost response to overshoot Daniel Hooke, Eleanor Burke, Camilla Mathison, Rebecca Varney, Norman Julius Steinert, T. Luke Smallman 3:10 - 3:30pm Discussion

	territory Oliver Geden, Andy Reisinger 3:00 - 3:12pm Towards a framework for aligning national mitigation scenarios with 1.5°C in an era of overshoot Hannah Daly, Róisín Moriarty 3:12 - 3:30pm Discussion	2:59 - 3:17pm Climate Change Mitigation Detectability using Machine Learning Models Assaf Shmuel, Kai Kornhuber, Niklas Schwind, Ron Milo, Carl Schleussner 3:17 - 3:30pm Poster pitches	
3:30 - 4:00pm	Coffee break		
4:00 - 5:30pm	Theme 2: Carbon dioxide Removal: Sustainability constraints and opportunities Location: Marshall Room 1 Matthew Gidden, Karl Scheifinger Theme: 2 Carbon dioxide Removal: Sustainability constraints and opportunities 4:00 - 4:10pm Introduction 4:10 - 4:25pm Afforestation Strategies under Climate Risk: Implications for Wood Supply and Long-Term Carbon Permanence Andrey Krasovskiy, Eunbeen Park, Hyun-Woo Jo, Colin Johnstone, Johanna San Pedro, Florian Kraxner 4:25 - 4:40pm CO2 Efflux In Logged-Over Area and Dipterocarpus Forest of Different Age In Nimbria Reserve Forest, Kaduna Nigeria. Hosea Kato Mande, Julius Bajji 4:40 - 4:55pm Optimal Control Analysis of Carbon Dioxide Removal Strategies and Overshoot Outcomes Nina Rynne 4:55 - 5:10pm Feedback for the Carbon Dioxide Removal Modelling Intercomparison Project (CDRMIP) in CMIP7 Nadine Mengis, Estela Monteiro, Jörg Schwinger, Anna Harper, Raffaele Bernardello 5:10 - 5:20pm Poster pitches	Theme 4: Climate impact (ir)reversibility Location: Theater Room Edward Byers, Debra Roberts Theme: 4 Climate impact (ir)reversibility 4:00 - 4:10pm Introduction 4:10 - 4:16pm Emulating the Effect of Overshoots on Regional Climate: an Impulse Response Function Approach D. M. Arrabali, Y. Quilcaille, L. Gudmundsson, R. Chitra, S. I. Seneviratne 4:16 - 4:22pm Overshoot and Solar Radiation Modification: The Limits of Climate Engineering for a Just 1.5°C Future Yi-Ling Hwong, Alexander Nauels, Thomas Frölicher, Yona Silvy, Carl Schleussner 4:27 - 4:42pm Heat-mortality impacts under 1.5°C overshoot pathways Samuel Lüthi, Ana Vicedo-Cabrera, Mireia Ginesta, Rupert Stuart-Smith 4:42 - 4:57pm How would Overshoot Impact Freshwater Hydrology and Water Resources? Adrienne Marshall, Emily Grubert, Sara Warix 4:57 - 5:12pm Overshoot, Irreversibility, and the Social Cost of Greenhouse Gases Daniel Johansson, Christian Azar, Thomas Sterner, Katsumasa Tanaka 5:12 - 5:30pm Discussion	Theme 6: Adaptation and adaptation limits under overshoot Location: Marshall Room 2 Marina Andrijevic, Kristie L. Ebi Theme: 6 Adaptation and adaptation limits under overshoot 4:00 - 4:05pm Introduction 4:05 - 4:15pm Modelling Overshoot, Missing Society: Political and Social Systems as Central Uncertainties in Climate Overshoot Pathways Elisabeth Gilmore 4:17 - 4:27pm Overshoot implications for human development and Loss and Damage financing massimo tavoni, Marta Mastropietro, Carlos Rodriguez Parro 4:29 - 4:39pm Understanding and addressing climate adaptation limits in the context of climate overshoot. Are there any hard social limits? Reinhard Mechler, L.M. Bouwer, Christian Huggel, Juhola Sirkku, Veruska Muccione, Ivo Wallimann-Helmer 4:41 - 4:51pm Climate overshoot implications for local adaptation planning Quentin Lejeune, Emily Theokritoff, Hugo Costa, Khadija Irfan, Mariam Saleh Khan, Chahan Kropf, Helena Gonzales Lindberg, Inês Gomes Marques, Inga Menke, Carl-Friedrich Schleussner, Adelle Thomas, Tiago Capela Lourenço 4:53 - 5:03pm Assessing the establishment of a network of heatwave refugia in Lisbon (Portugal) under overshoot trajectories Inês Gomes Marques, Kam Lam Yeung, Niels Souverijns, Chahan M. Kropf, Carl Schleussner, Tiago Capela Lourenço 5:05 - 5:30pm Discussion
6:00 - 6:30pm	Social dinner in Laxenburg Dinner speech by Dr. Jimmy Fletcher (Former Saint Lucia Minister with responsibility for Public Service, Sustainable Development, Energy, Science and Technology and Founder of the Caribbean Climate Justice Project)		

1st Oct 2025

9:00 - 10:00am	Report back & reflection session + transfer break Location: Theater Room 9.00-9.45: report back & reflection session 9.45-10.00: 15' transfer break		
10:00 - 11:30am	Theme 4: Climate impact (ir)reversibility Location: Theater Room Edward Byers, Debra Roberts Theme: 4 Climate impact (ir)reversibility 10:00 - 10:15am Irreversible risks to biodiversity after a 2°C temperature overshoot Andreas Schwarz Meyer, Alex Pigot, Joanne Bentley-McKune, Romaric Odoulami, Marcio Pie, Christopher Trisos 10:15 - 10:30am Humanitarian impacts of temporary climate overshoot: Irreversibility and little relief saskia werners, Edward Sparkes, Marie Weil, Simon Schwarzkopp, Ella Irena Therese Mroczek, Ji Sem Lau, Greg Puley, Zinta Zommers 10:30 - 10:45am Evolution of climate change risks in the context of 1.5°C overshoot – a conceptual framework Richard Betts, Carolina Adler, Jan Fuglestedt, Oliver Geden, Tom Johansen, Chris Jones, Shoba Maharaj, Angela Morelli, Anna Pirani, Elvira Poloczanska, Andy Reisinger, Sonia Seneviratne 10:45 - 11:00am The human and social impacts of climate overshoot Andrew Kruczkiewicz, Zinta Zommers, Joyce Kimutai, Matthias Garschagen, Joshua Fisher 11:00 - 11:30am Discussion	Theme 3: Earth System responses up to net zero and beyond Location: Marshall Room 1 Deliang Chen, Biqing Zhu Theme: 3 Earth System responses up to net zero and beyond 10:00 - 10:18am Marine carbon sink dominated by biological pump after temperature overshoot Wolfgang Koeve, Angela Landolfi, Andreas Oschlies, Ivy Frenger 10:18 - 10:36am Identifying changes in the El Niño-Southern Oscillation under net zero emissions Andrew King, Aditya Sengupta, Nicola Maher, Andrea Dittus, Mandy Freund, Tilo Ziehn, Eduardo Alastrué de Asenjo 10:36 - 10:54am Responses of spatial climate emulators to climate overshoots Yann Quilcaille, Michael Windisch, Camilla Mathison, Laila Gohar, Eleanor Burke, Chris Jones, Sonia I. Seneviratne 10:54 - 11:12am Long-run emulator calibration increases warming and sea-level rise projections Chris Wells, Chris Smith 11:12 - 11:30am Diagnosing Warming-Induced Emissions Greenhouse Gas Feedbacks Under Climate Overshoot (WIE-MIP) Benjamin Poulter, Pep Canadell, Phil Duffy, Robert Jackson, Chris Jones, Danielle Potocek	Theme 8: Legal and justice implications of overshoot Location: Marshall Room 2 Gaurav Ganti, Lavanya Rajamani Theme: 8 Legal and justice implications of overshoot 10:00 - 10:05am Introduction 10:05 - 10:15am Governance of «Overshoot»International Law for returning to 1.5°C (through global net-negative emissions) Christina Voigt 10:15 - 10:25am Justice Implications of Climate Overshoot: Mapping Responsibilities Across Mitigation, Adaptation, and Loss & Damage Shonali Pachauri, Setu Pelz, Caroline Zimm, Elina Brutschin 10:25 - 10:35am Legal constraints on solar radiation modification as a response to temperature overshoot Ewan White 10:35 - 10:42am Clarificatory questions & responses 10:42 - 10:52am growing up under overshoot: implications for climate litigation Wim Thiery, Nico Bauer, Amaury Laridon, Joeri Rogelj, Inga Menke, Chris Smith, Carl-friedrich Schleussner 10:52 - 11:02am Integrating attribution science to inform legal accountability for overshoot Carly Phillips, L. Delta Merner 11:02 - 11:30am Discussion
11:30am - 12:00pm	Coffee break		
12:00 - 1:00pm	Theme 2: Carbon dioxide Removal: Sustainability constraints and opportunities Location: Marshall Room 2 Matthew Gidden, Karl Scheifinger Theme: 2 Carbon dioxide Removal: Sustainability constraints and opportunities 12:00 - 12:05pm Introduction	Theme 8: Legal and justice implications of overshoot Location: Marshall Room 1 Gaurav Ganti, Lavanya Rajamani Theme: 8 Legal and justice implications of overshoot 12:00 - 12:04pm Introduction 12:04 - 12:16pm Schrödinger's Target in the European	Theme 1: Highest possible mitigation ambition under overshoot Location: Theater Room Annika Högner, Jarmo Kikstra, Joeri Rogelj Theme: 1 Highest possible mitigation ambition under overshoot 12:00 - 12:03pm Introduction 12:03 - 12:15pm The Sufficiency Gap: Why Germany, the

		12:05 - 12:20pm The role of enhanced CDR portfolio in the feasibility of an overshoot scenario under sustainability constraints Yoga Wienda Pratama, Sreyam Sengupta, Elina Brutschin 12:20 - 12:35pm Biodiversity implications of warming and land-intensive mitigation under different climate overshoot recovery assumptions Ruben Prütz, Sabine Fuss, Jeff Price, Rachel Warren, Nicole Forstenhäusler, Yazhen Wu, Andrey Lessa Derci Augustynczik, Michael Wögerer, Tamás Krisztin, Petr Havlík, Florian Kraxner, Stefan Frank, Tomoko Hasegawa, Jonathan Doelman, Vassilis Daioglou, Joeri Rogelj 12:35 - 12:50pm The role of Carbon Dioxide Removal in the Nationally Determined Contributions and Long-term Strategies Jay Fuhrman, Roan Chadsey, Yang Ou, Mel George, Haewon McJeon, Matthew Gidden, Detlef Van Vuuren, Catrin Harris, Vassilis Diaoglou, Yoga Pratima, Oumaima Rhalem, Hattie Whit, Sanna O'Connor-Morberg, William Lamb 12:50 - 1:00pm Discussion	Climate Law: Missed, Met, or Both? Martje Köppen 12:16 - 12:28pm Evaluating progress towards climate targets with consistent national remaining carbon budgets Konstantin Weber, Cyril Brunner, Reto Knutti 12:28 - 12:40pm Effect of discontinuous fair-share emissions allocations immediately based on equity Yann Robiou du Pont, Mark Dekker, Detlef van Vuuren, Michiel Schaeffer 12:40 - 1:00pm Discussion	Netherlands, and Norway's Cement Decarbonization Roadmaps Underachieve by Ignoring Demand-Side Measures Rosalie Arendt, Marc van den Berg, Daan Bossuyt, Felice Diekel, Jakob Napiontek, Peter-Paul Pichler, Patricia Schneider-Marin, Tim Verlaan 12:15 - 12:27pm Reducing the economy-wide costs of ambitious climate policies through agricultural carbon sequestration Stefan Frank, Oliver Fricko, Andrey Lessa Derci Augustynczik, Matt Gidden, Zuelclady Araujo-Gutierrez, Andre Deppermann, Mykola Gusti, Amanda Palazzo, Yazhen Wu, Petr Havlík, Volker Krey 12:27 - 12:39pm Missed opportunities & backsliding—agricultural methane, 'no additional warming' & global food system inequality Róisín Moriarty, Hannah Daly 12:39 - 12:51pm The Forgotten Sector: Agricultural Emissions and Highest Possible Ambitions under the Paris Agreement Katharina Neumann 12:51 - 1:00pm Discussion
1:00 - 2:00pm	-	Lunch Location: Oval Room		
2:00 - 2:45pm	-	Poster and networking market Location: Foyer Session 1 - Theme 1, 2 and 6 "Every Tenth of a Degree Matters": Translating Climate Ambition into Concrete Emissions Benchmarks Claire Fyson, Gaurav Ganti, Carl Schleussner CO2 Efflux In Logged-Over Area and Dipterocarpus Forest of Different Age In Nimbria Reserve Forest, Kaduna Nigeria. Hosea Kato Mande, Julius Bajji Realizing Carbon Dioxide Removals from German forests under increasing disturbance risk and overshooting (ForestOvershoot) Thirza van Laar, Hannes Böttcher, Allan Buras, Galina Churkina, Rico Fischer, Konstantin Gregor, Rüdiger Grote, Klaus Hennenberg, Ralf Kiese, Mats Nieberg, David Ohnmacht, Mirjam Pfeiffer, Anja Rammig, Judith Reise, Christopher Reyer, Nadine Rühr Climate change mitigation scenarios with temperature overshoot and broad CDR portfolio for use in ESMs Leon Merfort, Nico Bauer, Pasca Sauer, Jan Philipp Dietrich, Katarzyna Kowalczyk, Laurin Köhler-Schindler, Lavinia Baumstark, Gunnar Luderer, Robert Pietzcker, Robin Hasse,	Artistic Performances 14:00-14:40: Performative Lecture "The Road Not Taken (So Far)" by Gloria Benedikt @Theater Room 14:45-15:15: Audiovisual Performance "Eiszeit - wenn Orte verschwinden, denen ich nie begegnet bin" and "02: Wasser" by et art. collective @Marshall Room 1 15:00-ongoing: Audiovisual installation "What happens when collapse begins within?" by Mehrta Shirzadian @Marshall Room 2 15:00-ongoing: Performative installation "The last Capital Trust" by Lea Aigner and Rosalie Arendt @Theater Foyer	
2:45 - 3:45pm	-			Litigation Panel Discussion Location: Theater Room Climate science in litigation cases This panel will discuss recent climate litigation concerning government target-setting. In particular, panelists will discuss the role of scientific studies as evidence, and how science has informed the formulation of requests made by plaintiffs to courts. The discussion will also consider how these insights may influence further research, and how this might be used in future cases. Panelists: Dennis van Berkel — CLN Joeri Rogelj — ICL Michaela Krömer — BOKU Rupert Stuart-Smith University of Oxford April Williamson - CLN

		Johanna Hoppe, Anne Merfort, Gabriel Abrahão, David Klein, Michaja Pehl, Michael Crawford, Alexander Popp, Jessica Strefler, Elmar Kriegler Complimentary qualitative and quantitative methods for climate risk assessment and adaptation: Urban heat in Lisbon and Islamabad Jamie McCaughey, Khadija Irfan, Sumayya Ijaz, Mariam Saleh Khan, Inês Gomes Marques, Carolina Vieira, Hugo Costa, Niels Souverijns, Chahan M Kropf, Helena Gonzales Lindberg, Fahad Saeed, Tiago Capela Lourenço Urban Informal Settlements Uniquely Adapt to Flooding: Risk Convergencies in African Pathways Kareem Buyana Climate overshoot and Adaptation - The new policy frontier Oshea Roopnarian, Professor Shalini Singh Simulating the impact under climate overshoot and agronomic adaptation options for Summer Rice through DSSAT model Sarathi Saha, Saon Banerjee Mainstreaming overshoot considerations into adaptation planning: lessons from four regions around the world Zachary Zeller, Rosanne Martyr, Carl-Friedrich Schleussner, Sabine Fuss, Inga Menke, Tiago Capela Lourenço Limits to Urban Heat Adaptation Measures & Overshoot Implications Sylvia Schmidt, Ann-Katrin Peterson, Rosanne Martyr-Koller Adaptation pathways under overshoot scenarios Ann-Kathrin Petersen, Sylvia Schmidt, Rosanne Martyr Biodiversity conservation policies alter the solution space of climate mitigation scenarios Jan Steinhauser, Sreyam Sengupta, Jan Philipp Dietrich, Florian Maczek, Patrick von Jeetze, Oliver Fricko, Florian Humpenöder, Volker Krey, Michael Obersteiner, Alexander Popp, Keywan Riahi	
3:45 - 4:15pm	-	Poster and networking market Location: Foyer Session 2 - Theme 3 and 4	
4:15 - 4:30pm	-	Carbon Removal Under Overshoot: Evaluating the Combined effect of Land and marine CDR	
4:30 - 5:30pm	-	Anusha Sathyanadh, Helene Muri, Homa Esfandiari, Timothée Bourgeois, Jörg Schwinger, Tommi Bergman, Antti-Ilari Partanen, Miriam Seifert, David Keller	Austrian Panel Discussion Location: Theater Room Austrian Panel: "Austria in a World of Climate Overshoot: Risks, Opportunities, and

	Long-term net zero changes: European extremes, detectability, and a call for multi-model simulations Eduardo Alastrué de Asenjo, Andrew D. King, Tilo Ziehn, Nerilie J. Abram, Amanda C. Maycock, Alexander R. Borowiak, Spencer Clark, Nicola Maher Earth system responses to pathways that avoid temperature overshoots through stratospheric aerosol injections Jerry Tjiputra, Dirk Olivié, Jörg Schwinger, Norman Steinert, Nadine Goris, Rosie Fisher Response of the Earth system to the RESCUE overshoot scenarios: insights from OSCAR model Gaurav Shrivastav, Thomas Gasser Simple Climate Models can agree on everything but the carbon sink. Greta Shum, Olivia Truax, James Yoon, Dargan Frierson, Charles Koven, Abigail Swann Regional cooling of heat extremes in a net-zero world Andrea Rivosecchi, Andrea Dittus, Ed Hawkins, Reinhard Schiemann, Erich Fischer Differences in CDR representation between Integrated Assessment Models and Earth System Models Chiara Ciscato, Momme Butenschön, Tomas Lovato, Daniele Peano Title: Assessing the (Ir)reversibility of Climate Change Impacts in Southern Africa Malon Muronzi Do Environmental Sustainability Practices Shape Economic Performance in a Warming World? Empirical evidence through dynamic models. Zunaira Amin, Zulfiqar Shah, Abhijit Sharma Studying the mitigation and adaptation nexus under the risk of climate tipping Michael Freiberger, Michael Kuhn, Maddalena Muttoni, Stefan Wrzaczek Regional climate and carbon cycle irreversibility after overshoot NormanJulius Steinert, Jörg Schwinger, Hanna Lee Many reasons to safeguard the polar regions from dangerous geoengineering Marie Cavitte, Martin Siegert, Heidi Sevestre		Responsibilities” Lilian Schuster (University of Innsbruck) – Climate impacts, especially on glaciers and mountain regions Laila Kriechbaum (Fridays for Future Austria) Marc Olefs (ZAMG) Katharina Rogenhofer (Kontext)
6:30 - 7:30pm	Optional: Dinner in Vienna Stöckl im Park		

2nd Oct 2025

9:00 - 10:00am	Report back & reflection session + transfer break Location: Theater Room 9.00-9.45: report back & reflection session 9.45-10.00: 15' transfer break		
10:00 - 11:30am	Theme 7: Loss and Damage Location: Marshall Room 1 Elisa Calliari, Sindra Sharma-Khushal Theme: 7 Loss and Damage 10:00 - 10:05am Introduction 10:17 - 10:27am Resisting overshoot: Justice and repair in ecological loss and damage Emily Boyd, Richard Walters, Alicia N'Guetta 10:29 - 10:39am Financial Instruments as Signals and Mediators of Habitability in the Context of Temperature Overshoot Koko Warner, Kira Vinke, Mike Franczak, Michael Weisberg 10:41 - 10:51am Climate Overshoot and Insurance Retreat: Mapping Emerging Uninsurability in India, the Philippines, and Mexico Architesh Panda 10:53 - 11:03am Research Topic: The Future of Pastoralism in the Changing Climate and Modern Land Use Management in Kajiado County, Kenya. Sammy Oleku, Prof. Christopher Oludhe 11:05 - 11:30am Discussion	Joint session theme 4 & 5 Location: Theater Room Edward Byers, Jonathan Donges, Debra Roberts, Caroline Zimm 10:00 - 10:10am Introduction 10:10 - 10:25am A probabilistic risk assessment of interacting tipping elements under overshoot scenarios Jacques Bara, Wolfram Barfuss, Nico Wunderling 10:25 - 10:40am Threshold Breaching and Tipping Points in Impacts Alaa Al Khourdajie, Jonathan Moyer, Peter Alexander, Jonathan Donges, Kristie Ebi, Franziska Gaupp, Benjamin Gwinneth, Robin Lamboll, Minal Pathak, Joyashree Roy, Steven Sherwood, Caroline Zimm, Gabriele Hegerl 10:40 - 10:55am Global glacier response under overshoot Lilian Schuster, Fabien Maussion, David R. Rounce, Lizz Ultee, Patrick Schmitt, Fabrice Lacroix, Thomas L. Frölicher, Carl-Friedrich Schleussner 10:55 - 11:10am Towards overshoot-proof multi-century sea level projections – an emulator perspective Tessa Möller, Zebedee Nicholls, Jared Lewis, Carl-Friedrich Schleussner, Alexander Nauels 11:10 - 11:30am Discussion	Joint session theme 1, 2, 8 Location: Marshall Room 2 Gaurav Ganti, Matthew Gidden, Annika Högner, Jarmo Kikstra, Lavanya Rajamani, Joeri Rogelj, Karl Scheifinger States' dependence on carbon dioxide removal for achieving the Paris temperature goal: managing risks and strengthening transparency Rupert Stuart-Smith, Ewan White, Ruben Prütz, Joeri Rogelj, Thom Wetzer, Marianne Wood, Lavanya Rajamani Legal constraints on solar radiation modification as a response to temperature overshoot Ewan White
11:30am - 12:00pm	Coffee break		
12:00 - 1:00pm	Report back & reflection session Location: Theater Room		
1:00 - 2:00pm	Lunch Location: Oval Room		
2:00 - 3:00pm	Building Overshoot Narratives Location: Theater Room Poster Award Ceremony		
3:00 - 4:00pm	Closing and Poster Award Ceremony Location: Theater Room 3:00 - 3:05pm Poster Award Ceremony		

Artistic Performances

Eiszeit - wenn Orte verschwinden, denen ich nie begegnet bin – et art.

Listening, documenting, translating, mourning - tracing glaciers across emotional, somatic, and geological layers. Eiszeit - wenn Orte verschwinden, denen ich nie begegnet bin is an audiovisual performance which explores the landscape and sensory dimensions of the glacier Schlatenkees in East Tyrol and the significance of its retreat for the surrounding environment and population. In this journey, the audience will hear texts abstracted from the impressions gathered during the artistic research process, accompanied by instrumental improvisations shaped by the glacial soundscape. The acoustic dimensions are complemented by film footage, showing excerpts from the field research that the et art. collective conducted at Schlatenkees in September 2023. The performance is based on outcomes of the collective's project 02: Wasser and premiered in January 2024 during the solo exhibition fluid by the artist Helena Detsch at Mohr-Villa in Munich.

02: Wasser

02: Wasser is an audio-visual zine by the artist collective et art. The study Evolution of debris cover on glaciers of the Eastern Alps, Austria, between 1996 and 2015 (F. Fleischer et al., 2020), dealing with the effect of the climate crisis on the glacier retreat in Austria and the role of water in the change of landscape, served as the scientific point of departure for creative engagement within a multi-disciplinary artistic process.



About et art.

et art. is an Austria based artist collective that uses artistic strategies to connect scientific knowledge with emotional experience, opening up new ways to engage with effects of the climate crisis. Working with selected research on climate in Austria, et art. develops audio-visual and literary translations of scientific papers and thus initiates innovative, interdisciplinary climate narratives. Current members of the collective are Cornelia Dirnberger (Master Visual Communication, University of Art and Design Linz), Konstantina Maria Hornek (Master Expanded Museum Studies, University of Applied Arts Vienna / Master European Ethnology, University of Vienna), Christian Prohammer (Bachelor Harpsichord / Basso Continuo, University of Music and Performing Arts Graz), and Johanna Unterpertinger (Master Recorder, CNSMD Lyon / Master Historical Bassoons, HEM Geneva).

The Last Capital Trust (LCT) – A Performative Installation by Lea Aigner & Rosalie Arendt

At The Last Capital Trust (LCT), we know that nature has been our first and will be our last capital. Our mission is to transform natural and climate-related resources into sustainable capital, fostering innovative solutions for a healthier planet. We actively support young changemakers, climate researchers, and pioneering companies, empowering them to develop impactful projects that address urgent challenges. At LCT, we aim to create a resilient and sustainable future for all. LCT is an ecomodernist project. It is a community and a network of those who embrace change. Because in change, we trust.

Lea Aigner and Rosalie Arendt are interested in the capitalization of nature and the cash flows within the climate sector. They critically question why certain narratives, such as the “climate overshoot,” are promoted and what economic interests may lie behind them.

In their performative installation, Lea Aigner and Rosalie Arendt envision a fictional, cult-like foundation called “The Last Capital Trust” (LCT), which offers support to researchers and companies engaged with sustainability and working on solutions for the climate crisis. At the Overshoot Conference, this foundation would present itself at a market-like space with a small stand that aesthetically blends with other formats at a scientific conference and its sponsors. Lea Aigner and Rosalie Arendt will perform as representatives of LCT, engaging with conference visitors. They will advocate for the best solutions against the climate crisis (from CO vacuums for home use to climate change detox capsules), offer CO₂ cookies (captured and stored through eating), provide climate stress tests and climate counseling (as we know, fighting a crisis can wreck your nerves), and feature a confessional box (for your worst climate sins).

About

Lea Aigner is a performance and installation artist as well as a policy maker, currently serving as a scientific advisor in the Berlin City Parliament with a focus on mobility politics. She holds a Master's degree in Politics, Media, and Performance from Aberystwyth University (UK), and both a Bachelor's and a Master's degree in Stage Design from Berlin University of the Arts (GER). In her artistic practice, Lea works both collaboratively and solo, exploring the intersection of arts, politics, nature, and science. She experiments with various media, drawing on her background in visual arts and stage design. Her work has been showcased at venues such as Uni.T Berlin, BAT Studio Theatre, and Gregynog Ideas Lab. Lea has engaged with various themes including climate politics, feminism, and computer games, blending her artistic and policy interests to foster meaningful dialogue. A long-lasting collaboration and friendship with scientist Rosalie Arendt, with whom she has already created artistic theater projects during her early days of study, broadens her horizons and continually prompts her to ask new questions.

Dr.ing- Rosalie Arendt is an Assistant Professor in Carbon Neutrality and Life Cycle Assessment at the University of Twente (UT). Her research explores the boundaries of emission reduction potential—identifying which emissions are avoidable versus unavoidable (residual) in the transition to net-zero. Prior to joining UT, she completed her PhD at the Technical University of Berlin, developing methodologies to translate LCA environmental impacts into monetary values. Her core work advances environmental quantification methods and examines how these approaches enable or hinder policy implementation for socioecological transformation. Beyond her technical research, she brings a creative lens to climate discourse: her climate-focused poetry gives voice to the human dimensions of ecological crises, while her background in theater—cultivated through productions during her studies in collaboration with Lea Aigner—strengthens her ability to communicate complex scientific narratives and engage diverse audiences in the urgency of systemic change.

What Happens When Collapse Begins Within? - Mehrta Shirzadian

This video and sound installation turns inward to explore how climate overshoot reverberates through the intimate ecosystems of the body. Focusing on the vaginal microbiome, a sensitive and hormonally regulated internal ecology, the work uses microbiological imagery and soft sound to reflect on bodily responses to environmental stress, heat, and systemic imbalance.

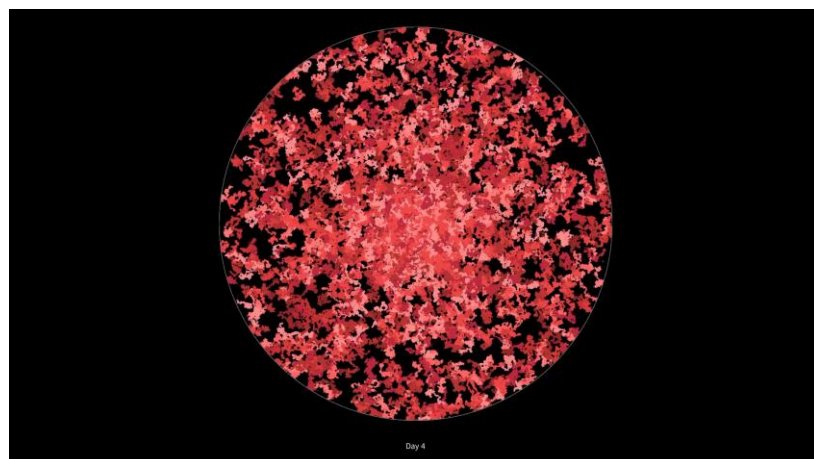
Projected time-lapse videos of microbial growth, collected across a full menstrual cycle, become both personal archive and ecological metaphor. The images are cast directly onto a bed of compacted soil, connecting the body's internal bacterial life with the Earth's microbial skin. Accompanied by an ambient soundscape of low bodily tones, hums, and decaying rhythms, the installation invites viewers into a quiet space of microbial memory and cyclical intelligence.

Scientific research increasingly shows that microbial health is impacted by rising temperatures, pollution, and psychosomatic stress. Just as heat alters soil and ocean microbiomes, it also affects the microbial balance inside our bodies. Scientists use soil microbiomes to monitor ecosystem health. This work suggests we can listen inward just as attentively. What happens when collapse begins within?

The piece proposes the body as a site of climate encounter, one where transformation is not only visible in landscapes and charts, but in cycles, symptoms, and bacterial shifts. It offers a feminist, embodied approach to ecological storytelling: one that lets climate overshoot speak from the insideout.

About

Mehrta Shirzadian is a Vienna-based performer, multimedia artist, and molecular biologist. Her interdisciplinary practice merges artistic research, microbiological experimentation, and embodied performance to explore themes of intimacy, decay, and ecological transformation. She is currently completing her MA in Art & Science at the University of Applied Arts Vienna and has presented work at venues such as Ars Electronica, MQ Summer Stage, and Reallabor Fassfabrik. Her current work investigates the vaginal microbiome as both a scientific subject and a poetic system for understanding transformation in times of climate and societal stress.

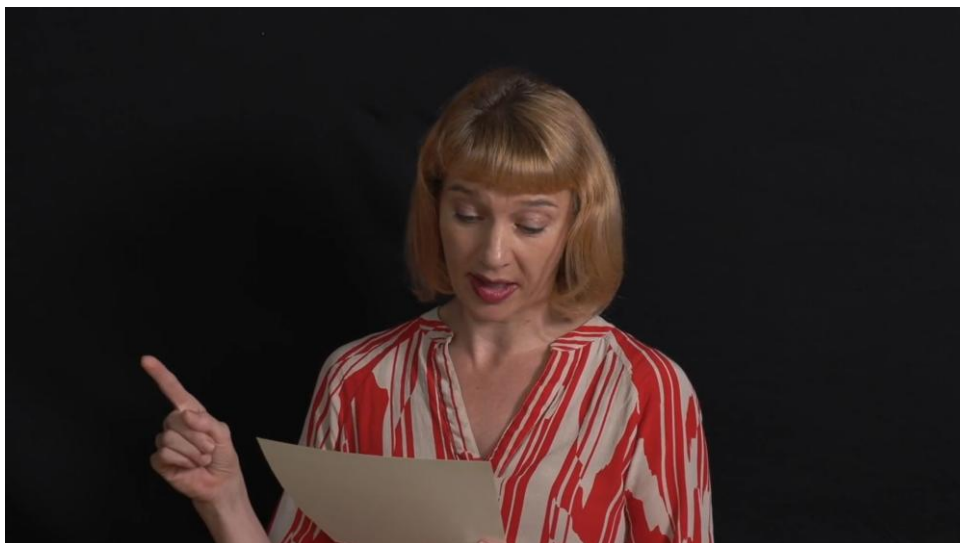


The Road Not Taken (so far) - Gloria Benedikt

The Road Not Taken (so far) is a performative lecture set in 2050. A performative lecture is a presentation based on an academic paper woven into a fictional plot. It explores questions raised by young scientists (born in 2025; young scientists in 2050). Specifically, they want to know what happened to the green dream where fossil fuels are kept in the ground, renewable energy can meet the needs of the global population, multilateral cooperation thrives, peace is the norm, both the economy and technology serve people rather than the other way around, resources are shared equally, humans respect planetary boundaries, indigenous peoples' wisdom influences government policies, and nature has rights because respecting nature's dignity is essential for respecting the dignity of all people. Benedikt will attempt to answer their questions and discuss the role culture, and narrative art in particular, can play in shifting away from planetary overshoot.

About

Gloria Benedikt is a research artist and stage director. In 2015, she joined the International Institute for Applied Systems Analysis (IIASA) to explore how partnerships between scientists and artists can support the transformation toward sustainability. She is the author of *Science and Art for Life's Sake* (2020) and was a Visiting Fellow at the Institute for Human Sciences (IWM). She has co-produced and directed numerous multimedia productions and presented her work at theaters, international institutions, festivals, and conferences including the Bridging Europe Festival, Carnegie Hall, the European Commission's Joint Research Center, the European Culture Forum, the European Forum Alpbach, the European Parliament, Harvard University, Institute de France, Institute Pasteur, the Kennedy Center Washington, the UNESCO Forum, the UNGA and the World Science Forum. She has co-curated the UN Concert for a Sustainable Planet. For over a decade, she has worked on cultural and science diplomacy initiatives with the Austrian Ministry of Foreign Affairs, and most recently, also with the European External Action Service (EEAS) in Mexico and Japan. Teaching assignments include the Mellon Summer School for Performance Research at Harvard University, the IIASA Young Scientists Program, and the School for Modern Diplomacy, co-organized by the Diplomatic Academy Vienna and the United Nations University.



The Overshoot Conference Podcast series

The conference will be structured around eight themes, each capturing a key dimension of the interdisciplinary challenge of climate overshoot. Every theme is led by an internationally recognized expert in the field:

Highest possible mitigation ambition under overshoot

Carbon dioxide removal: sustainability constraints and opportunities

Earth system responses up to net zero and beyond

Climate impact (ir)reversibility

Overshoot legacy and tipping elements

Adaptation and adaptation limits under overshoot

Loss and damage

Legal and justice implications of overshoot

Together, these themes reflect the wide scope of inquiry needed to address not only the physical aspects of climate overshoot, but also its social, ethical, and political consequences.

To make these themes more accessible to a broader audience, the themes are introduced through a podcast series released in the weeks leading up to the conference. The first episode features Carl-Friedrich Schleussner, who provides an introduction to the topic and the conference.



Episode 1: Climate Overshoot – An Introduction with Carl Schleussner

Theme 1: Highest possible mitigation ambition under overshoot

Chair: Joeri Rogelj, Jarmo Kikstra, Annika Högner

The Paris Agreement – in Article 4.3 – requires countries to pursue their “highest possible ambition” in their Nationally Determined Contributions (NDCs), while reflecting principles of equity and fairness. With the world on track to surpass 1.5°C of global warming, the meaning of Paris alignment is increasingly challenged. This session examines how the legal, political, and practical interpretation of highest possible ambition must evolve in the face of overshoot. Bringing together scholars, analysts, and practitioners from diverse disciplines, we invite contributions that explore the implications of Article 4.3 (ever higher ambition of NDCs, reflecting ‘highest possible ambition’) in this new climate reality. How should ambition be assessed in light of historical emissions? What responsibilities in terms of ambition arise for countries that have exceeded their fair share of atmospheric space? How can climate governance adapt to ensure accountability and equity? By reframing ambition through the lens of a 1.5°C overshoot, this session seeks to redefine pathways for meaningful climate action in an era of deepening crisis.



Episode 2: Highest Possible Ambition under Overshoot with Joeri Rogelj

Missed opportunities & backsliding—agricultural methane, ‘no additional warming’ & global food system inequality

Róisín Moriarty^{1,2}, Hannah Daly^{1,2}

¹Sustainability Institute, University College Cork, Cork, Ireland. ²School of Engineering and Architecture, University College Cork, Cork, Ireland

Abstract

With only two and a half years of carbon budget remaining, rapid, deep and sustained reductions in greenhouse gas (GHG) emissions over the next decade—particularly immediate methane reductions—are necessary to slow near-term warming, limit temperature overshoot, keeping ‘low warming’ carbon budgets in reach, and reduce reliance on carbon dioxide removal (CDR).

Countries with well above-average per capita methane (CH₄) emissions have a clear opportunity to increase ambition and contribution to limiting near-term warming by reducing CH₄ emissions.

This raises key questions: what happens when countries, like Ireland, with well above-average per capita CH₄ emissions driven by large-scale dairy and beef production, adopt ‘no additional warming’ approaches based on temperature neutrality (TN) to set agricultural CH₄ reduction targets? How do these approaches stack up against the ambition of the Paris Agreement and considerations of equity and fairness?

We use the reduced complexity climate model MAGICC to quantify Ireland’s future national warming contributions under four scenarios: (1) business-as-usual or achieving either (2) TN or (3) a split-gas emissions target or (4) net-zero GHG emissions by 2050. After which, a set of agri-food indicators is used to contextualise the global food equity implications of a TN approach.

The TN approach requires the lowest overall GHG reductions and implies reduced need for CDR than higher ambition split-gas or net-zero pathways. However, sustained TN associated with CH₄ is not achieved in any scenario, particularly the TN and less ambitious split gas approach.

The TN approach obscures the broader agricultural and land system transformation required to achieve outcomes observed in the more ambitious scenarios. Maintaining TN is highly sensitive to assumptions related to global CH₄ trends, creating a moving target that lacks transparency. This risks an over reliance on anticipated short-term CH₄ reduction and potentially misdirecting climate policy by underestimating the long-term need for CDR.

TN approaches are often justified through reference to aligning climate mitigation with food security; however, these claims fall short under scrutiny. This analysis demonstrates that high income producers primarily serve high-income markets and rely on imported feed to sustain ‘meat security’, potentially creating land and resource pressures in lower-income countries.

Ireland is committed by national legislation to support the achievement of Article 2 of the Paris Agreement, and Ireland’s Climate Change Advisory Council claims that its carbon budgets are consistent with the objective of limiting warming to 1.5°C. However, if all countries adopted a TN approach to CH₄ emissions, limiting warming to 1.5°C becomes impossible and 2°C becomes much more difficult. Proliferation of this approach risks missing a critical opportunity

to reduce peak warming, undermining the global mitigation effort, and delaying the food system transformation needed to enable sustainable agricultural development where it is most urgently required.

Keywords: climate neutrality, temperature neutrality, Paris Agreement, carbon budget, agriculture methane, climate justice, food security

Energy-material dynamics define highest-ambition pathways

Harald Desing

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Abstract

Upscaling ambitions requires increasing material and energy investments in renewable energy infrastructure and negative emissions ([www.doi.org/10.1088/1748-9326/ac36f9](https://doi.org/10.1088/1748-9326/ac36f9)). These investments are physically limited by the dynamically available energy supply and raw material production capacities within planetary boundaries. Considering biophysical constraints and feedbacks, this talk will explore possible strategies to limit overshoot and soonest return to 350ppm ([www.doi.org/10.1029/2022ef002875](https://doi.org/10.1029/2022ef002875)) with explorative modelling based on energy-material feedback dynamics: building renewable energy infrastructure needs materials and the production of materials needs energy ([www.doi.org/10.1016/j.resconrec.2023.107314](https://doi.org/10.1016/j.resconrec.2023.107314)).

When investing all available energy and material capacity, the fastest possible transition can limit overshoot to about 1.6°C (<https://doi.org/10.21203/rs.3.rs-5974514/v1>). Energy storage plays a decisive role in this, as more energy storage leads to higher investments—especially in critical raw materials such as Li, Co, Ni, graphite, Pt—, delays the transition, and leads overall to higher cumulative emissions. Consequently, the better society can align its energy demand with the availability of renewable energy (Sunflower Society, [www.doi.org/10.1007/s41247-022-00097-y](https://doi.org/10.1007/s41247-022-00097-y)), the faster the transition can be achieved and the lower peak cumulative emissions become.

After the transition, returning to 350ppm necessitates the removal and permanent storage of at least 400 Gt of carbon ([www.doi.org/10.1039/d2va00168c](https://doi.org/10.1039/d2va00168c)). Nature based solutions can take up parts of this carbon; however, scale and speed of ecosystem removals are limited by biological dynamics and competition for food and other material use of biomass. Furthermore, they are also required for compensating residual emissions and for ecosystem restoration. Accelerating the clean-up of excess CO₂ beyond the ecosystem's removal capacity, could be feasible technically when using excess peak renewable power for direct air capture. Storing CO₂ over geological timescales is, however, challenging and an "end-of-pipe" solution representing a cost to society. The idea of Mining the Atmosphere ([www.doi.org/10.1016/j.resconrec.2024.107968](https://doi.org/10.1016/j.resconrec.2024.107968)) aims at converting atmospheric CO₂ into valuable solid materials. The material use of atmospheric carbon can replace conventional materials as well as create an economic possibility to transform into a carbon binding society. From the perspective of energy and materials, it could still be feasible to return to 350ppm before the end of this century. Defining highest possible ambition strategies allows to prioritize investments, identify physically critical system elements, and can help design innovative policies.

The Forgotten Sector: Agricultural Emissions and Highest Possible Ambitions under the Paris Agreement

Katharina Neumann

University of Oxford, Oxford, United Kingdom

Abstract

Several scholars interpreting the Paris Agreement argue that states are obligated to pursue rapid emissions reductions to minimise any overshoot of the 1.5°C temperature target (Stuart-Smith et al. 2023, Ekardt et al. 2022). To achieve this objective, the global reduction of emissions in *all* sectors is essential (Allen et al., SPM). Despite this, agricultural emissions remain mainly unaddressed in mitigation actions. Rather, states classify a large amount of agricultural emissions as hard to abate, framing them as residual emissions (Buck et al. 2023). However, all IPCC emissions reduction pathways consistent with 1.5°C include reductions of agricultural emissions. As other sectors are decarbonising more rapidly, continued agricultural emissions pose a significant obstacle to meeting the Paris Agreement's 1.5°C target, which indicates that agricultural emissions reductions will become increasingly vital.

However, this is not reflected in states' mitigation efforts. While many NDCs and LT-LEDs from developed countries broadly acknowledge the need to reduce agricultural emissions, (i) they rarely set specific reduction targets for the sector, and (ii) even when they do, they often lack credible, detailed plans to achieve projected reductions. This is underscored by the 2024 NDCs Synthesis Report, which indicates that agricultural emissions continue to go unaddressed, and policy coverage is limited. A 2024 FAO report further reveals an implementation gap in the sector, with commitments in NDCs failing to translate into action. States are therefore less ambitious in pursuing short-term emissions reductions in the agricultural sector compared to other sectors, largely based on the assumption that substantial ongoing agricultural emissions can be maintained beyond their net-zero target dates. However, this strategy is precarious, relying heavily on large-scale carbon dioxide removal, the feasibility of which remains uncertain.

Against this background, this paper seeks to assess the level of ambition that states' NDCs should embody with respect to agricultural emissions. It argues that subsequent agreement to the Paris Agreement in the form of COP decisions suggests that states agree that they must ensure mitigation across *all* sectors, *including* agriculture, to reach the 1.5°C goal. The paper asserts that this influences the standard of due diligence under the Paris Agreement, which determines whether states have pursued their 'highest possible ambition'. To discharge the due diligence standard, states must put in place necessary measures to address emissions from the agricultural sector.

Given the lack of robust mitigation in the agricultural sector, some states, particularly those with greater responsibility for agricultural emissions and a higher capacity to reduce them, may not be pursuing their 'highest possible ambition' and may therefore be failing to meet the due diligence standard under the Paris Agreement. To do 'their utmost' to address climate harms, states must adopt measures that are meaningful, timely, and effective, rather than continually overlooking robust, near-term mitigation in agriculture. A breach of the due diligence standard may give rise to consequences under the law of state responsibility, which constitutes this paper's final focus of analysis.

The Sufficiency Gap: Why Germany, the Netherlands, and Norway's Cement Decarbonization Roadmaps Underachieve by Ignoring Demand-Side Measures

Rosalie Arendt^{1,2}, Marc van den Berg¹, Daan Bossuyt³, Felice Diekel¹, Jakob Napiontek², Peter-Paul Pichler², Patricia Schneider-Marin⁴, Tim Verlaan⁵

¹University of Twente, Enschede, Netherlands. ²Potsdam Institute for Climate Impact Research, Potsdam, Germany. ³Utrecht University, Utrecht, Netherlands. ⁴Norwegian University of Science and Technology, Trondheim, Norway. ⁵University of Amsterdam, Amsterdam, Netherlands

Abstract

Cement is essential for modern infrastructure but produces 5-8% of global CO₂, with process emissions that fuel substitution alone cannot reduce. Meeting the Paris Agreement's call for "highest possible mitigation ambition" requires exploring every decarbonization pathway, including reducing demand. However, cement sector roadmaps, while acknowledging deep decarbonization needs, overwhelmingly treat demand as fixed and residual emissions as technically inevitable.

To assess how actors define and justify residual emissions, we analyze decarbonization roadmaps of the cement sector (strategic documents from government, industry, and civil society outlining sectoral pathways) for Germany, the Netherlands, and Norway—countries selected for their high floorspace per capita, a key indicator of significant potential for demand-side sufficiency strategies. Using qualitative document analysis, we code 30 decarbonization levers identified iteratively from roadmaps and literature, categorized via a cement-specific Mitigation Hierarchy (Avoid, Reduce, Reuse, Replace, Minimize, Capture and Store, Offset).

Our findings expose a persistent sufficiency gap: roadmaps prioritize incremental technical solutions (e.g., novel binders, clinker substitution) and speculative carbon storage (e.g., CCS), while neglecting transformative measures like material reuse, alternative construction methods, or demand-side strategies (e.g., spatial efficiency policies, cooperative housing). By excluding demand mitigation (e.g., treating per capita cement demand as exogenous at 200–400 kg/year), roadmaps artificially inflate residual emissions. The Dutch Betonakkord marginally addresses circularity, and older German pathways hint at efficient space use, but none integrate sufficiency levers systematically.

The consequences are profound: by framing high material demand as immutable, roadmaps lock in carbon-intensive development pathways and defer responsibility to unproven technologies. This contradicts the Paris Agreement's equity and ambition principles, which demand interdisciplinary integration of mitigation strategies.

Residual emissions are not inevitable but politically constructed. Truly Paris-aligned pathways must challenge demand growth through collaboration across engineering, industrial ecology, social sciences and urban history. Without this shift, our reliance on speculative technical measures risks not achieving climate targets.

Fair Share Emissions Allocations

Yann Robiou du Pont^{1,2}, Mark Dekker¹, Detlef van Vuuren¹, Michiel Schaeffer³

¹Utrecht University, Utrecht, Netherlands. ²Data Driven Envirolab, Chapel Hill, USA. ³Universitas Islam Internasional Indonesia, Depok, Indonesia

Abstract

National emissions targets are collectively insufficient to align with the Paris Agreement. The literature assesses whether these targets are ‘fair and ambitious’ in comparison to emissions trajectories based on equity principles. Such emissions trajectories commonly start at present-day emissions levels. This study finds that these ‘continuous’ trajectories inherently reward past inaction and increasingly do so with their iterative updates. Here we provide a novel approach to allocating emissions trajectories based on equity principles applied with immediate effect. The resulting discontinuous national trajectories not starting at current emissions levels imply significant immediate international support to fund rapid mitigation globally. Modelling allocations with or without continuity has remarkable consequences for the relative implied contributions among high-income countries to international support. We find that targets of G7 countries, Russia and China are responsible for most of the global 2030-ambition gap, while only some countries in the Global South align with their 1.5°C allocation.

Fair-share approaches immediately based on equity applied to socioeconomic pathways offer an alternative to simply accounting for countries climate debt. These approaches provide country-level emissions pathways that address start addressing inequities immediately through international cooperation and alleviate the reliance on future negative emissions. Such approaches provide relevant information to decision makers and courts when considering targets that may include international cooperation and are collectively consistent with a global socioeconomic pathway.

Towards a framework for aligning national mitigation scenarios with 1.5°C in an era of overshoot

Hannah Daly, Róisín Moriarty

University College Cork, Cork, Ireland

Abstract

While global integrated assessment models produce scenarios compatible with stabilising warming at 1.5°C, to what extent can – and do – national models? As the global community increasingly acknowledges that overshoot of 1.5°C is imminent, the interpretation and application of "highest possible ambition" as mandated by Article 4.3 of the Paris Agreement becomes critically important at national scales.

Recent [commentary](#) by Glen Peters underscores that global scenarios involving “impossibly steep emission declines to 1.5°C” offer limited practical guidance. Instead, more nuanced national scenarios, reflecting specific country circumstances and feasible ambition, are urgently needed. Achieving 1.5°C globally thus hinges on radical mitigation actions primarily implemented at the national level - scenarios that are “harder for researchers, but more confronting for policy makers”.

This paper addresses critical questions: Are national modelling and analytical frameworks adequately equipped to produce scenarios genuinely aligned with a 1.5°C future, particularly in the era of overshoot? What blind spots and methodological challenges hinder alignment? How can fairness, feasibility, and political acceptability be effectively reconciled in developing these scenarios?

Drawing from our experience working at Ireland’s “science-policy interface”, we propose a comprehensive set of criteria that national models and analytical frameworks should meet to credibly generate 1.5°C-aligned scenarios.

Ireland’s climate law requires legally binding carbon budgets aligned with the Paris Agreement. These budgets have been underpinned by iteratively-developed modelled pathways for energy, land-use, and food systems. Our experience highlights significant challenges in genuinely aligning these frameworks with the stringent demands of a 1.5°C future, and have succeeded, in our view, only partially.

Drawing from these lessons, the proposed framework encompasses four key elements:

1. Alignment with 1.5°C & transparent equity assessment: Clearly define and justify how national emission and removal pathways contribute fairly to a global 1.5°C outcome, explicitly reflecting equity principles such as historical responsibility, capability, and equality. Given overshoot realities, frameworks must address not just emissions reductions but equitable responsibilities for carbon drawdown and non-CO₂ mitigation, especially for high-income countries with historical carbon debt. Consider the role of methane reduction to limit peak warming

2. Expanded mitigation space & feasibility: Explore broader mitigation spaces, including radical demand reduction and structural changes beyond incremental technology substitution. Explicitly assess:

- Expanded CDR options

- ☐ Maximum plausible clean technology diffusion
- ☐ Low-demand scenarios
- ☐ Explicit mitigation of residual emissions

3. Coverage of greenhouse gases and sectors: Include all relevant sectors and gases typically underrepresented in national scenarios, such as Agriculture, Forestry and Other Land Use (AFOLU), international aviation and shipping, bioenergy, hydrogen trade, and short-lived non-CO₂ gases.

4. Integration and sectoral coherence: Ensure coherent integration across sectors, particularly regarding land use, sustainable resource use and management of biogenic carbon (and its role in carbon drawdown, bioenergy, terrestrial carbon sinks and CDR), and reflecting integrated land-energy-food system interactions.

This framework aims to shift the Overton window towards scenarios genuinely reflective of the "highest possible ambition" in the critical decade ahead, aligning national actions transparently and fairly, to better confront policymakers with choices and trade-offs.

How just can we be? Increased European ambition across sectors is required to achieve a fair share of atmospheric space and limit overshoots

Jacob Mannhardt, Leo Behmel, Giovanni Sansavini

ETH Zürich, Zürich, Switzerland

Abstract

A limited carbon budget remains to stay within a 1.5°C increase of the global surface temperature. While the physical basis for the remaining global carbon budgets is established, the fair allocation of the budget to individual regions is disputed. The European Union (EU) has positioned itself as a climate leader, advocating for ambitious climate policies and, through them, globally just climate futures. On the world stage, the EU has been instrumental in ensuring the signing of key treaties and has long advocated for a globally fair energy transition.

In this study, we analyze if and how the European energy transition can be aligned with globally climate-just decarbonization pathways to allocate the remaining atmospheric space fairly. Using the open-source energy system optimization framework ZEN-garden, we model sector-coupled European transition pathways to meet 1.5°C goals. We find that European decarbonization will struggle to deliver a globally just decarbonization: transitions that consider right-to-development, ability-to-pay, and historical responsibilities all seem technically impossible. Overshoots can be avoided when following a grandfathering or egalitarian approach; however, these principles are problematic because they overlook Europe's historical role in causing emissions to drive development and economic growth.

At the same time, our results support that moving towards more equitable outcomes entails only moderate cost increases. Therefore, we show that European policymakers can help reduce overshoots more ambitiously without inflicting grave financial damage.

The practical increase of ambition to pursue climate-justice compatible transitions requires European policymakers to take responsibility along three fronts. First, Europe should target immediate carbon emission reduction in the electricity, heating, and transport sectors, and subsequent electrification of as many sectors as possible. The road transport sectors, in particular, offer the most accessible opportunity for ambitious emission reductions. Second, a balanced biomass strategy must become a cornerstone in industrial sectors, where currently no direct electrification options are available. Third, Europe should prepare for high installation of direct air capture (DAC) units between 2040 and 2050 as a last resort to offset remaining emissions from industrial sectors, such as aviation and cement production.

Overall, our results support previous observations of a clear credibility and ambition gap in European climate policy. However, this study outlines practical steps to reduce the overshoot and move towards more equitable and ambitious pathways.

“Every Tenth of a Degree Matters”: Translating Climate Ambition into Concrete Emissions Benchmarks

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Abstract

The message “every tenth of a degree matters” is increasingly used in climate science outreach to highlight the escalating impacts of seemingly small increments of global warming. The phrase was first introduced by the IPCC to summarise the findings of its latest assessment reports and emphasise that if warming exceeds 1.5C, all effort must be made to limit overshoot to as low as possible. This framing has since been widely used by organisations such as UNEP and the UNFCCC secretariat, as well as government representatives and scientists to underscore the urgency of tackling climate change. But while there is a good understanding of the degree to which impacts worsen with each increment of warming, how this translates into mitigation requirements is less clear. Such information is important for connecting the dots between the desire to avoid more dangerous impacts and the near-term emissions reduction targets and policies set out by governments.

Here, we address this gap by using existing emissions pathways developed by integrated assessment models, complimented by simplified synthetic pathways, to shed light on what a tenth of a degree warming looks like in terms of delayed emissions cuts. For example, we explore how many years delay in achieving a global peaking of emissions would commit us to 0.1 degrees of additional warming, compared to a peak before 2025. Another relevant benchmark is the timing of halving global CO₂ emissions. By translating a tenth of a degree of warming into clear and understandable emissions benchmarks, we aim to provide more conceptual clarity on the implications of a failure to achieve ‘highest possible ambition’ in NDCs and mitigation policies, which will continue to be highly relevant in an overshoot world.

The institutional and socio-cultural feasibility of entering net-negative territory

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Abstract

Returning to 1.5°C after having exceeded this level requires reaching and sustaining net-negative CO₂ emissions globally. This will not be possible without a considerable number of countries aiming for deep levels of net-negative CO₂ emissions on a national level, with developed countries expected to take the lead in going beyond the net-negative CO₂ levels already implied by their current net-zero GHG targets. But while in recent years such demands have sporadically been made by developing countries (e.g. the BASIC group), this has not captured much of the attention in global and national climate policy debates, let alone on the sectoral level. Nor have major historical emitters — such as the United States, the United Kingdom, or the European Union — articulated promises or presented robust plans for going deeply net-negative, neither in Long-Term Strategies nor in Nationally Determined Contributions under the UNFCCC.

Our presentation will explore barriers and enablers to close the current ‘ambition gap’ by shifting the long-term focus beyond net-zero emissions at three interconnected levels: (1) international (in UNFCCC and global environmental assessments like IPCC or UNEP reports); (2) national (particularly developed countries and emerging economies); (3) sectoral (particularly in net-negative frontrunner countries). We will also explore potential pitfalls for the eventual implementation of deeply net-negative ambitions.

Multi-dimensional mitigation milestones for peak warming outcomes

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Abstract

With annual global mean temperatures reaching 1.5°C, and international cooperation on mitigation overshadowed by discussions on climate finance, further clarifying the shrinking climate mitigation landscape to limit warming is paramount. The integrated modelling scenarios provide a key reference point to discern emission and other mitigation milestones, yet their sampled solution space is relatively sparse. Here, we present a new machine learning approach that harnesses the large scenario databases to systematically fill the solution space. For example, this allows decision makers to evaluate various global stocktake conclusions - such as tripling of renewable energy capacity in the interplay with methane reduction targets or timelines for fossil-fuel phase out - as well as translating these into milestones for multiple time horizons. Our analysis finds, for example, that limiting peak warming to below 1.7°C is possible if CO₂ emissions are reduced at or beyond 55% in 2035 (65% in 2040) compared to 2019, CH₄ emissions reductions at or beyond 30% in 2035 (40% in 2040), installed renewable energy capacity above 12 TW in 2035 (16TW in 2040) and large-scale CDR application emerging between 2035 (0Gt/yr) and 2040 with about 1.5Gt/yr in 2040, ramping up to 3 Gt/yr in 2050. These multi-dimensional milestones are then compared to maximum-ambition feasibility estimates in the scientific literature.

The analysis can be repeated for alternative peak temperatures, or adapted to account for the magnitude and duration of overshoot. Furthermore, while applied here to currently publicly available IAM scenarios, this methodology can be rapidly adapted to and refined by adding next-generation scenarios to the training data set. The decision to include or exclude scenarios from the training data set that can no longer be considered feasible in light of the trajectory of global greenhouse gas emissions in the recent past is an important consideration here.

Net Zero Aligned International Carbon Markets under the Paris Agreement

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Abstract

A sustainable and accelerated net zero transition requires deep domestic emission reductions alongside scaling increasingly durable removals. Removals can be used to both compensate for residual emissions and contribute to drawdown (Azar et al., 2010; Rogelj et al., 2018; Caldecott & Johnstone, 2024). However, to date, we are witnessing a growing removals gap (Smith et al., 2024), with near-term trends pointing to the immediate challenge of scaling up these technologies in line with ambitious mitigation pathways that limit climate overshoot (Fuhrman et al., 2025).

In this context, we explore possible futures for scaling carbon dioxide removal through different operationalisations of Article 6 of the Paris Agreement, which creates a flexible cooperative framework for participating countries to meet and enhance the ambition of their climate targets through emissions trading. Its two market-based frameworks, Articles 6.2 and the Paris Agreement Crediting Mechanism (under Article 6.4), create a quasi-compliance international carbon market, in which participants can voluntarily trade mitigation outcomes to meet their Nationally Determined Contributions (NDC) or other climate commitments, such as net zero targets under Long Term – Low Emission Development Strategies (LT-LEDS). Whereas there are arguments that flexible emissions trading may provide the necessary finance to scale carbon dioxide removal, in its current design, Article 6 does not differentiate between reductions and removals, nor does it address the systemic risks and opportunities associated with the trading of each. To date, the trading of removals within this framework remains low.

Here we explore a gradual phased transition towards a permanent removals-only future for Article 6. Such a thought experiment examines the implications of different market structures and regulations on closing the removals gap and, in turn, minimising the magnitude and duration of climate overshoot. In particular, we examine how these mechanisms could support achieving and enhancing the ambition of up-to-date NDCs in terms of both their conditional and unconditional components.

This article addresses a current lack of scholarship on the net-zero alignment of market-based mechanisms under Article 6 and on the role of such mechanisms in scaling up carbon dioxide removal. It fills an important gap by exploring options for urgently needed system redesign in the context of the breadth of the Paris Agreement and the urgency of achieving its outcomes.

Reducing the economy-wide costs of ambitious climate policies through agricultural carbon sequestration

Stefan Frank¹, Oliver Fricko¹, Andrey Lessa Derci Augustynczik¹, Matt Gidden², Zuelclady Araujo-Gutierrez¹, Andre Deppermann¹, Mykola Gusti¹, Amanda Palazzo¹, Yazhen Wu¹, Petr Havlík¹, Volker Krey¹

¹IIASA, Laxenburg, Austria. ²PNNL, Seattle, USA

Abstract

Improved management practices to enhance carbon in agricultural soils are considered a promising cost-effective mitigation strategy. Yet, these practices and their potentials have not been considered in the global mitigation pathways developed by Integrated Assessment Models (IAM) and examined in the Working Group 3 6th Assessment Report (AR6) of the Intergovernmental Panel on Climate Change while policy makers around the world are starting to consider them in their climate policies and commitments to achieve targets. Here, we assess the economy-wide impact of three agricultural carbon sequestration options (enhanced soil carbon sequestration on agricultural land, biochar application, and the establishment of silvo-pastures) if considered in a global climate policy using the MESSAGEix-GLOBIOM integrated assessment model. By contrasting different climate stabilization pathways that do or do not consider these practices with varying adoption rates, we examine the climate and economic implications, spillover effects across economic sectors as well as inter-temporal dynamics such as delayed adoption of these agricultural practices.

We show that agricultural carbon sequestration options represent a no-regret option for climate policy design as they substantially improve the economy-wide cost-efficiency of GHG mitigation efforts. Conditional on the climate policy design, these options offer the potential to substitute more costly CO₂ abatement technologies in hard-to-abate sectors including energy- and industry which could result in a 35% decline in global GHG prices by 2040. Alternatively, these options could also speed up the transition towards global net zero CO₂ emissions by compensating residual GHG emissions and thereby reduce total cumulative CO₂ emissions across all sectors by some 160 GtCO₂ by 2100 as compared to the benchmark climate stabilization scenario without these options. As a result these options can help to achieve global net zero emissions ten years faster and thereby curb temperature overshoot by mid-century or reducing GHG prices and thereby easing GDP losses associated with climate stabilization efforts in the short-term. We show that Delayed availability of these options would shift their benefits towards mid-century. However, next to institutional and other non-economic barriers to adoption that would need to be overcome, climate finance should address inequalities across all world regions to reap these mitigation potentials since potentials are mainly located in the Global South.

Theme 2: Carbon dioxide Removal: Sustainability constraints and opportunities

Chair: Matthew Gidden, Karl Scheifinger

CDR approaches vary broadly from regrowth of natural biomes to engineered extraction and ultimate storage of CO₂ from the atmosphere to geologic repositories. Each approach has its own unique challenges in terms of scalability, effectiveness, and durability of ultimate storage. In particular, resource requirements and environmental footprints may be limiting factors for future large-scale CDR deployment. In this session, we invite a wide range of talks focused on how CDR can be scaled sustainably, what are the trade-offs with other mitigation activities, and where are synergies which can accelerate overall net emissions reductions, with a focus on robust strategies that can hedge against key uncertainties such as risk of reversibility or carbon rerelease in multiple phases of climate overshoot. We encourage submissions from topics including enabling conditions and barriers related to e.g., markets, policies, finance, feasibility, verification of removals, and public perceptions.



Episode 3: Carbon dioxide Removal: Sustainability constraints and opportunities with Keywan Riahi

CO₂ Efflux In Logged-Over Area and *Dipterocarpus* Forest of Different Age In Nimbia Reserve Forest, Kaduna Nigeria.

Hosea Kato Mande, Julius Bajji

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Abstract

The uptake of carbon dioxide by terrestrial ecosystems is critical for moderating climate change. To provide a ground-based long-term assessment of the contribution of forests to terrestrial CO₂ uptake, measurement was conducted in forests of different ages and logged-over areas. The aim was to assess the total CO₂ efflux into the atmosphere and storage capacity of forest of different ages. The measurement of CO₂ flux was carried out using two modified continuous open flow soil CO₂ efflux Chamber technique and three sets of air stabilizers for ambient air, all connected to a multi-gas handle unit which is designed to completely eliminated the air pressures created between the soil and the interphase of soil CO₂ efflux, and this was monitored from the installed barometer. Measurements of soil temperature, soil moisture, water potential, soil CO₂ efflux and ambient air CO₂ were conducted simultaneously. The result revealed that higher percentage of soil CO₂ efflux was recorded in the logged-over area with an average range of soil CO₂ efflux from February to June, 2024 at 103.26 to 475.37 mg m⁻² h⁻¹ and a declined rate in efflux from September to December, at a range of 151.34 to 462.24, 123.16 to 368.76, 113.77 to 353.00 and 138.96 to 345.85 mg m⁻² h⁻¹ respectively, attributed to slash wood, root decay and change in soil properties. The 10-year-old recovering forest was found to emit an average efflux range between February to June, 2024 , and September to December, 100.22 to 553.40 mg m⁻² h⁻¹ and 115.33 to 536.00 mg m⁻² h⁻¹ respectively. The average soil CO₂ efflux in the 30-year-old recovering *Dipterocarp Baudii* and *Verruscusus* tree species in the tropical forest from February to June 99.23 to 520.58 mg m⁻² h⁻¹ and September to December, 2024 witnessed an efflux rate of 500.22 mg m⁻² h⁻¹ in September and decreased to 478.53, 458.00 434.97 mg m⁻² h⁻¹ in October, November and December, 2024. The average soil CO₂ efflux recorded in the 50-year-old recovering forest from the month of February to June ranges from 100.13 to 634.78 mg m⁻² h⁻¹. Soil CO₂ efflux continued to decrease as it was observed between September and December at a range of 212.00 to 424.89, 177.47 to 394.64, 188.56 to 378.78 and 141. 44 to 368.78, mg m⁻² h⁻¹ respectively. The 70-year-old forest of 10 mixed tree species emitted soil CO₂ efflux rate at an average of 92.09–619.67 mg m⁻² h⁻¹. September to December efflux decreased at 152.79 to 528.67, 120.97 to 500.73, and 106.77 to 472. 89 and 122.89 to 452. 89 mg m⁻² h⁻¹ at an average efflux of 106.77 to 528. 67 mg m⁻² h⁻¹ from September, October, November and December 2024 respectively. In conclusion, soil CO₂ efflux in the mixed tree species forest demonstrated a significant variation as a function of logged-over and recovering forest. Soil CO₂ efflux of the logged-over area was remarkable higher than the recovering forest and decreased with forest age indicating high carbon storage and high physiological activity by roots as temperature played a key role.

Feedback for the Carbon Dioxide Removal Modelling Intercomparison Project (CDRMIP) in CMIP7

Nadine Mengis¹, Estela Monteiro¹, Jörg Schwinger², Anna Harper³, Raffaele Bernardello⁴

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Abstract

Most future scenarios that limit global warming to below 2°C by 2100 rely on the large-scale implementation of carbon dioxide removal (CDR) measures. While CDR is increasingly recognized as a key component of climate change mitigation, its representation in Earth system models (ESMs) remains limited and often lacks the details required to capture key processes and feedbacks. This constrains our ability to assess the efficacy, side effects, and system-wide implications of CDR within climate mitigation pathways.

A new phase of the Carbon Dioxide Removal Model Intercomparison Project (CDRMIP) is now being launched for CMIP7. It aims to address key scientific questions including:

1. How effective are (activity-driven) CDR implementations in terms of removal efficiency, what carbon–climate feedbacks do they trigger, and what are their expected side effects including biophysical effects; and how does this vary under net-positive, net-zero and net-negative emissions?
2. What are the discrepancies between integrated assessment model (IAM) scenarios, typically based on reduced-complexity climate models, and fully coupled ESMs when CDR is explicitly represented? How do these mismatches affect assessments of additionality and interactions among different CDR options within mitigation portfolios?

This poster will introduce the aims and design of the upcoming CDRMIP phase and present the experimental protocol for CDRMIP. It is meant to offer a platform to share and discuss the experimental design and invites feedback on the proposals. We also welcome coordination needs for the success of CDRMIP and opportunities for community collaboration moving into CMIP7.

Optimal Control Analysis of Carbon Dioxide Removal Strategies and Overshoot Outcomes

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Abstract

With the near-inevitable overshoot of the Paris Agreement 1.5°C target, understanding how trade-offs between carbon dioxide removal (CDR) strategies affect overshoot magnitude and duration becomes crucial for establishing CDR ambitions. This research presents an optimal control framework that explicitly separates emissions reduction and CDR strategies to investigate how different model assumptions and deployment strategies affect optimal CDR timing and volume.

Our simplified model enables systematic exploration of how key assumptions influence CDR deployment decisions and resulting overshoot characteristics. Through comprehensive sensitivity analysis varying CDR costs, deployment delays, discount rates, and climate sensitivity, we reveal how changing assumptions alter how emissions reduction and CDR strategies evolve over time.

Results demonstrate how different CDR deployment strategies can lead to potentially catastrophic overshoot conditions, with certain parameter combinations resulting in peak temperatures and durations that may exceed thresholds for ecosystem viability and species survival. This demonstrates the urgency of early implementation as delays lead to substantially higher temperature outcomes.

While our simplified model has important limitations, its modular structure and mathematically robust solution methods provide a tractable foundation for understanding how model assumptions influence CDR ambitions under overshoot scenarios. This offers insights into relationships between CDR deployment decisions and overshoot characteristics that could inform future development of more comprehensive frameworks for evaluating CDR scaling strategies.

States' dependence on carbon dioxide removal for achieving the Paris temperature goal: managing risks and strengthening transparency

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Abstract

Achieving the Paris Agreement's long-term temperature goal of limiting global warming well-below 2°C while pursuing efforts to limit it to 1.5°C requires rapid and sustained reductions in greenhouse gas emissions and CO₂ to be withdrawn from the atmosphere and safely stored. However, pathways consistent with the Paris long-term temperature goal span a wide range of emission reductions in coming years: the IPCC indicates 34-60% cuts in greenhouse gas (GHG) emissions between 2019-2030. This range is a major source of policy uncertainty. A key determinant of the rate at which emissions must be reduced this decade is the extent to which CO₂ removal (CDR) is relied on later to withdraw emissions from the atmosphere.

In an analysis of 71 states' near and long-term climate strategies submitted to the UNFCCC, we find substantial ambiguities in how states plan to meet their climate targets. A feature of this ambiguity is that states expect to rely heavily on novel and conventional CDR options to meet their climate goals, and in some cases, rely on removals delivered in other states' territories, yet rarely articulate how risks to the delivery of this CDR will be managed. In addition, pathways that overshoot 1.5°C and use CDR to remove emissions produced in excess of the 1.5°C-aligned carbon budget will result in more severe climate change impacts and higher risks of crossing planetary tipping points. States' disclosed reliance on CDR is highly exposed to risks to its delivery, and non-delivery of planned CDR would raise global temperatures further, worsening impacts of climate change.

These findings raise questions about how the risks of high levels of, or ambiguous, CDR dependence should be managed, including under international law. Ultimately, the risks associated with excessive CDR dependence can be reduced by more stringent mitigation action in the near term, greater transparency in relation to reporting and monitoring of CDR use, and ensuring feasibility and coherence in the planned deployment of CDR.

Realizing Carbon Dioxide Removals from German forests under increasing disturbance risk and overshooting (ForestOvershoot)

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Abstract

Carbon dioxide removal (CDR) by the forest sink and storage in wood products (hereafter 'Forest CDR') are two key elements to create negative emissions in Germany. They play a crucial role in achieving climate neutrality, especially through the provisioning of long-lived wood products for the construction sector. However, forests also face climate impacts, which have dramatically increased recently and led to decrease in forest productivity and substantial amounts of damaged timber that can not be easily used for conventional construction products. This interaction of climate impacts on forests and their long-term mitigation potential is especially relevant in an overshooting context where low-cost, strong Forest CDR is required later in the century to compensate for higher emissions earlier in the century, that also are likely to come along with stronger extreme events affecting forests. Projections of the German forest sink and harvested wood product (HWP) carbon storage are required that capture these intricate interactions and can provide an uncertainty range for future Forest CDR projections.

We will present the CDRterra II project ForestOvershoot (starting in September 2025), the aim of which is to evaluate and quantify the potential for, and timing of, Forest CDR options in Germany under an overshoot scenario, considering uncertainties due to climate change, forest disturbances and other forest management objectives. In the project we will employ state-of-the-art forest and wood product modeling, life-cycle analysis (LCA) as well as carbon cycle assessments of innovative timber buildings. We will quantify the negative emissions generated by Forest CDR under a range of forest disturbances, forest management, forest protection and forest conversion in an overshooting context. The forest models use harmonized input data, model set-ups and scenarios so that they can be compared, ensembles calculated and uncertainties related to model processes assessed. Moreover, key ecosystem services and biodiversity are simulated and ForestOvershoot uses multi-criteria optimization techniques to quantify trade-offs of Forest CDR with ecosystem services. Trade-offs are particularly analyzed in an overshooting context where strong climate impacts on forests are expected, as well as an increasing need for long-lived HWPs to generate additional negative emissions.

Biodiversity conservation policies alter the solution space of climate mitigation scenarios

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Abstract

Climate change and loss of biodiversity are two urgent aspects of the polycrisis that confronts us today. Some climate change mitigation measures, such as forest protection, expansion, and re-wilding of former croplands and pastures, also have beneficial effects on biodiversity. However, there are other land-based climate mitigation methods, such as cropland expansion for Bioenergy with Carbon Capture and Storage (BECCS), that require large amounts of land and thus potentially reduce the amount of land available for nature. In this study, we use an interlinked system of land-use (MAgPIE), energy systems (MESSAGEix), and climate (MAGICC) models to explore the co-benefits and trade-offs in scenarios of biodiversity conservation and climate mitigation. We find that emphasizing biodiversity conservation incentivizes the energy system to invest in efficiency increases and decarbonization early on (before mid-century), and a lot of near-term emissions are avoided. Conversely, when biodiversity is not a concern, the energy system can afford to decarbonize more slowly, since there is potential for immense carbon dioxide removal (CDR) through BECCS in the latter half of this century. In terms of temperature, the former choice has beneficial effects on temperature trajectories, limiting the probability of overshoot beyond 2 °C above pre-industrial temperatures to 25%, while the latter choice increases the corresponding probability to 50%. Thus, we find that biodiversity conservation, and the accompanying rapid decarbonization and increase in efficiency of the energy system, can serve to limit the extent of overshoot.

The role of Carbon Dioxide Removal in the Nationally Determined Contributions and Long-term Strategies

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Abstract

In the decade since the Paris Agreement, the expected role of carbon dioxide removal (CDR) in limiting end-of-century temperature increase to “well-below 2C” has grown substantially. CDR will be critical to reduce net greenhouse gas (GHG) emissions in the short to medium-term, and to compensate for carbon budget overshoot in the longer term by enabling net-negative global emissions. Despite this, most countries remain vague about how they will deliver the large-scale removals implied in their Nationally Determined Contributions (NDCs) and Long-Term Strategies (LTS) under the UNFCCC. To the extent that countries have considered CDR in these submissions, they have generally relied heavily on an expansion of their land carbon sink by increasing forest area. Others have used bioenergy with carbon capture and storage (BECCS) as a proxy for all CDR. However, relying solely on these CDR pathways could lead to unacceptable strain on the land system, and/or reversibility risks. Alternative methods, such as direct air carbon capture and storage (DACCS), enhanced rock weathering (ERW), and biochar (BC), offer the prospect of higher durability and/or near-term scalability.

These shortcomings stem in part from the representation (or lack thereof) of CDR technologies by integrated assessment models (IAMs), which have long informed IPCC Working Group III reports and national decarbonization strategies. First, only recently have models begun to represent CDR pathways beyond BECCS and afforestation on a widespread basis. Second, scenarios often use stylized global emissions pathways and/or end-of-century warming targets, which do not necessarily reflect real-world policy commitments across nations. Critically, rate and growth limits for different CDR approaches, or enabling technologies such as geological carbon storage, are not considered in a systematic matter for individual countries or regions in these scenarios.

To begin addressing these limitations, we present the results of a 3-model intercomparison study on the role of a portfolio of CDR in the NDCs and Long-term strategies. The GCAM, IMAGE, and MESSAGE models were each updated to expand the representation of CDR technologies, and to reflect plausible but ambitious near-term deployment limits on geological carbon storage, enhanced weathering, and bioenergy. Each modeling team ran two policy scenarios consistent with the Unconditional NDCs submitted to the UNFCCC as of June 2025. In the first, countries and regions must achieve their NDCs domestically, using a combination of emissions reductions and CDR. In the second scenario, countries can engage in global emissions trading under a prospective Article 6 framework, allowing them to meet their targets through a mix of domestic action and international cooperation.

Scaling a diverse CDR portfolio could prove even more critical to meeting the Paris goals, given recent policy fluctuations and the increased likelihood of high temperature overshoot. As countries submit update their NDCs in advance of the 2025 Conference of Parties, these results can help inform a more explicit consideration and realistic role of different CDR technologies in their decarbonization goals. They may also help support the development of Article 6 agreements to drive more cost-effective CDR deployment.

Afforestation Strategies under Climate Risk: Implications for Wood Supply and Long-Term Carbon Permanence

Andrey Krasovskiy, Eunbeen Park, Hyun-Woo Jo, Colin Johnstone, Johanna San Pedro, Florian Kraxner

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Abstract

Climate change is one of the main drivers of extreme wildfires globally, and their extent and frequency are projected to increase under future global warming scenarios. Therefore, these risks must be considered when planning adaptation and mitigation strategies for forests.

We apply an integrated modeling approach that links the Global Forest Model (G4M) with the wildfire climate impacts and adaptation model (FLAM). The forest dynamics and disturbance modules are interconnected through a dynamic integration process, supported by a newly developed fuel module.

Outputs from this combined modeling framework—including forest structure variables from G4M, burned areas and fire intensity from FLAM—are exchanged annually between the modules.

This integrated framework enables the assessment of adaptation and mitigation strategies at multiple scales, providing quantified projections of biomass, carbon dynamics, and disturbance impacts under future climate scenarios.

We apply this approach to model afforestation scenarios across four major biomes: boreal, temperate, dry tropics, and humid tropics. For each biome, we develop scenarios for both fast- and slow-growing representative tree species. Forest growth is simulated over a 300-year period, under scenarios both without disturbances and with wildfire risks, considering SSP1-2.6 and SSP5-8.5 climate pathways.

This modeling framework offers a valuable foundation for evaluating carbon dioxide removal (CDR) options and assessing long-term carbon permanence under climate risk.

Biodiversity implications of warming and land-intensive mitigation under different climate overshoot recovery assumptions

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Abstract

Biodiversity loss is expected to escalate with every increment of global warming. Simultaneously, land-intensive mitigation strategies, such as afforestation and bioenergy, may further compound biodiversity loss. So far, the magnitude of these two drivers has not been compared in the context of temperature overshoot, meaning the temporary exceedance of a targeted global warming limit. By combining spatial data on climate refugia (areas that protect biodiversity against climate change), bioenergy cropland, and afforestation for multiple cost-effective scenarios with varying levels of climate action and overshoot, we illustrate warming-related and mitigation-related implications for climate refugia existing today across four integrated assessment models. More ambitious mitigation actions result in higher land allocation within today's climate refugia due to larger reliance on land-intensive mitigation. Still, decisive climate action, compatible with limiting warming to 1.5 °C, reduces the warming-related loss of today's climate refugia by more than 50% compared to current climate policies, outweighing potentially negative implications of mitigation at the global level. Already by 2030, around 19% of today's climate refugia would be lost due to warming across all considered scenarios and model frameworks, whereas similar levels of mitigation-related land allocation within today's climate refugia would only arise towards the end of the century. We observe notable differences across regions and the considered model frameworks, while overshoot implications strongly depend on the underlying biodiversity recovery assumptions after peak warming. Our illustrative analysis shows that ecosystems would not only need to recover from overshoot but also deal with altered mitigation-related land use within climate refugia, implying that a world at 1.5 °C after overshoot is different from a world at 1.5 °C before overshoot.

The role of enhanced CDR portfolio in the feasibility of an overshoot scenario under sustainability constraints

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Abstract

Overshoot scenarios have been increasingly considered in climate mitigation pathways. This is due to the growing challenge of achieving the Paris Agreement targets, caused by delayed actions in reducing CO₂ emissions. As a result, there is an increase in reliance on CO₂ removals (CDRs), both conventional and novel methods, in the second half of the century. However, how quickly and how much CDRs can be deployed remain uncertain. In this work, we assess the impact of these factors on the feasibility of an overshoot scenario, using the MESSAGEix-GLOBIOM integrated assessment model. CDR potentials from BECCS, DACCS, biochar, biomass burial, enhanced rock weathering (ERW), and ocean alkalinity enhancement (OAE) are taken into account. We analyse the impact of CO₂ storage, biomass, and rocks for ERW and OAE availabilities on the scenario feasibility, and the role of CDR technologies in substituting other CDR methods as the latter become less available. We found that the availability of biomass and CO₂ storage significantly affects the feasibility of the overshoot scenario, as many CDR methods rely on these resources. In cases with stringent sustainability constraints, i.e., limited biomass and CO₂ storage availabilities, enhanced rock weathering and ocean alkalinity enhancement may allow for a feasible overshoot scenario. Notwithstanding this, it would require ambitious removal targets from these technologies in the near term, which suggests that the availability of a larger number of CDR methods, thereby increasing the overall capacity for CO₂ removal, does not warrant delaying efforts to mitigate climate change.

Climate change mitigation scenarios with temperature overshoot and broad CDR portfolio for use in ESMs

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Abstract

The door to 1.5°C closes rapidly and exceeding this target set by the Paris agreement, at least temporarily, may become inevitable in only a few years. Large-scale Carbon Dioxide Removal (CDR) may facilitate a drawdown of temperatures after reaching the peak, however, neither a) economic implications of such an overshoot pathway nor b) the consequences for the earth system are well understood.

Using an Integrated Assessment Model (IAM), we derive a set of eight climate change mitigation scenarios with and without overshoot for further use in Earth System Models (ESM) to assess earth system feedbacks. Here we focus on the IAM results, contrasting the consequences of overshoot and non-overshoot pathways for the energy and land system transformation.

We find that the substantially higher levels of CDR in an overshoot scenario are facilitated through a large portfolio of options featuring afforestation and reforestation, Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Carbon Capture and Storage (DACCS) and Ocean Alkalinity Enhancement (OAE). Depending on the stringency of the CO₂ budget, maximum annual CO₂ injection rates need to be 2.5 to 5 times higher in the case of an overshoot. Interestingly the required ramp-up speed of geological carbon storage is, with annual capacity additions of up to 500 Mt CO₂ between 2030 and 2040, only slightly lower in the 1.5°C compatible no overshoot scenario than the highest observed rates in the overshoot scenario (600 Mt CO₂ annually between 2070 and 2100). Thus, even though the CDR economy needs to maintain high growth for a longer period in an overshoot case, high growth rates are also required for cost-efficiently reaching the Paris targets without overshoot.

Comparing scenarios that reach 1.5°C by 2100 with less ambitious (ca.) 1.8°C scenarios, we find that overshoot and non-overshoot pathways perform completely different with respect to the timing of global net-zero CO₂ emissions. For a 1.5°C global warming target, an overshoot delays the net-zero timing by 21 years from 2041 to 2062. For 1.8°C, in the non-overshoot pathway net-zero CO₂ emissions only need to be achieved by 2100, while still reaching that target after an overshoot requires net-zero CO₂ emissions already by 2077, i.e. 23 years earlier. Delaying near-term mitigation thus leads to a dangerous lock-in, in which even less ambitious climate targets require huge mitigation efforts in the second half of the century.

Reviewing assumptions and transparency of CDR modelling in long-term scenarios

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Abstract

Building a wide auditing infrastructure for climate change modelling is a key step towards achieving greater transparency and accountability in climate economics.

An auditing approach is proposed to review scenarios of energy system transition with a focus on the representation of carbon dioxide removal (CDR) technologies. The framework promotes an inspection of scenarios and of scenario ensemble, allowing to define their taxonomy and classification in a format useful to support decision-making in the promotion of policies and investments in key CDR technologies, such as Direct Air Carbon Capture and Storage (DACCS) as well as Bioenergy with Carbon Capture and Storage (BECCS). Considering the design of scenario and ensembles, the need for scenario auditing is first highlighted with reference to alternative fields such as the Artificial Intelligence one. In addition, in the development and deployment of CDR technologies, audit tools will be presented to assess the scenario credibility and policy-relevance. In the analysis, not only CDR development will be considered but also its interplay with low-carbon technologies, such as renewable energy. The proposed framework is generic and can be used for classifying scenarios and inspecting their credibility on different dimensions (such as population, Gross Domestic Product, renewable energy, etc.) beyond existing vetting methods. The scenarios submitted to the Sixth Assessment Report of the IPCC will be used in addition to those developed by other public and private institutions, as a basis to assess the data input accessibility and availability as well as to stress-test the usefulness of the methodology. The discussion will highlight the potential for a combined use of quantitative and qualitative tools for auditing scenarios and ensembles. Additionally, key areas for future methodological research will be highlighted including new benchmarks and machine learning tools.

Theme 3: Earth System responses up to net zero and beyond

Chair: Deliang Chen, Biqing Zhu

Uncertainties in the Earth System Response during and after overshoot remain substantial and will determine the potential for reversing global warming. Factors influencing the transient response up to net zero CO₂ emissions will determine the level of peak warming and thus the extent of the overshoot and its associated impacts. A key question is whether the Earth System responds differently to global net negative emissions compared to the period leading up to net zero. This will affect how much and how quickly global temperatures could decline, as well as the amount of carbon dioxide removal (CDR) required. In this session, we welcome a wide range of contributions focusing on improving our understanding of the Earth System response up to net zero and beyond. These may include whole Earth System perspectives, but also contributions focusing on specific components such as the carbon cycle. Submissions providing emerging insights from the observational record in the context of overshoot are also welcomed.



[Episode 4: Earth System responses up to net zero and beyond with Deliang Chen](#)

Climate Change Mitigation Detectability using Machine Learning Models

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Abstract

Earth's climate is rapidly changing due to anthropogenic activity. Current mitigation efforts remain insufficient to reverse the current trajectory. While existing research has demonstrated the long-term (~25 years) benefits of mitigation, its short-term effects (~10 years) remain uncertain. Some studies even suggest that no meaningful difference between best- and worst-case scenarios can be detected within this timeframe, a conclusion that risks discouraging policymakers, who often prioritize immediate benefits over distant outcomes. We challenge this assumption, hypothesizing that mitigation benefits can be detected much earlier than previously thought. Instead of assessing the global climate as a whole, as in past studies, we leverage high-resolution gridded climate data to analyze mitigation impacts at the regional level. This approach ensures that no critical information is lost in aggregation.

In this study we apply machine learning (ML) to classify between mitigation and non-mitigation scenarios, aiming to determine the earliest point at which mitigation effects become distinguishable. Unlike traditional statistical approaches that primarily rely on global mean temperature trends, ML enables the detection of subtle, spatially heterogeneous signals by leveraging the full gridded structure of climate model outputs. This allows us to identify early regional indicators of mitigation, which may emerge long before global temperature differences become statistically significant. ML is particularly well suited for this task due to its ability to analyze high-dimensional climate datasets and uncover complex, nonlinear patterns that traditional methods might overlook. This allows the model to detect localized warming patterns that may emerge earlier than the global average, particularly in highly sensitive regions such as the Arctic, Europe, and other climate hotspots.

Furthermore, we incorporate explainability techniques to interpret the ML model's decisions, revealing which geographic regions and climate variables contribute most to early scenario differentiation. This information is crucial for identifying the regions that benefit most from mitigation efforts and providing policymakers with actionable insights. By applying ML in this context, we aim to demonstrate that the effects of mitigation can be detected much sooner than previously thought, reinforcing the urgency and effectiveness of climate action.

In addition to baseline mitigation pathways, this method could also be suitable for identifying overshoot trajectories – those in which global temperatures temporarily exceed climate targets before stabilizing or declining. These scenarios are increasingly relevant, as they reflect delayed but intensified mitigation. The approach could be applied to ensemble datasets such as AERA-MIP to assess whether overshoot pathways can be distinguished from non-overshoot ones. If successful, this would offer valuable insight into the detectability of overshoot-related signals, particularly during the peak warming period. Such information could support adaptation planning and improve our understanding of the near- and mid-term consequences of temporary climate target exceedances.

Carbon Removal Under Overshoot: Evaluating the Combined effect of Land and marine CDR

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Abstract

With the global annual mean temperature in 2024 exceeding 1.5°C above preindustrial levels, the world faces increasing risks from climate impacts. Achieving the long-term temperature goals of the Paris Agreement will require not only deep emission reductions but likely also large-scale deployment of carbon dioxide removal (CDR). However, major uncertainties remain regarding the Earth system's response to CDR, its efficacy under overshoot conditions, and the potential of CDR to reverse warming beyond net-zero emissions.

Here, we use emission-driven simulations with activity-driven implementation of CDR in the Norwegian Earth System Model (NorESM2-LM) to assess the carbon sequestration efficacy and climate response of two CDR methods, Bioenergy with Carbon Capture and Storage (BECCS) and Ocean Alkalinity Enhancement (OAE), deployed individually and in combination. Our scenarios follow a high-overshoot trajectory (SSP5-3.4-OS) combined with ramped-up deployment of CDR. Additional CDR amounted to 5.2 million km² of bioenergy feedstock for BECCS in addition to the BECCS already present in the SSP5-3.4-OS and a CaO deployment rate of 2.7 Gt/year for OAE, derived from life cycle analysis. OAE is applied across the exclusive economic zones of Europe, the United States, and China. BECCS alone accounts for a 16 ppm reduction using 5.2 million km² of bioenergy crops, while OAE contributes 7 ppm reduction with a cumulative addition of 82.3 Gt of CaO, yielding a CDR effectiveness of 0.08 ppm per Gt of CaO. During the overshoot phase (2050–2060), the combined simulation shows a gross atmospheric CO₂ reduction of 2–4 ppm, increasing to a reduction of 23 ppm by 2100, indicating nearly additive contributions from the two methods.

Despite the substantial CO₂ drawdown and a net reduction of anthropogenic emissions by 5.4 GtCO₂/year by 2100 through additional CDR, the global temperature response remains modest and indistinguishable from internal variability. This highlights the importance of designing robust, scalable CDR portfolios along with ambitious emission cuts. Our results also call for better integration of CDR pathways into IAMs scenarios so that we can have them in ESMs to fully capture biogeophysical feedback and Earth system constraints in overshoot scenarios.

Long-term net zero changes: European extremes, detectability, and a call for multi-model simulations

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Abstract

There are increasing scientific efforts to understand how the climate changes under net-zero carbon dioxide emissions. In the long term, new idealised extended Earth System model simulations signal at net-zero changes that play out over centennial timescales, with increased long-term impacts for delayed emissions mitigation [1]. There are, however, many aspects of these centennial changes that need further scrutiny. In this contribution, we bring together the results from three ensuing publications on these idealised 1000-year-long net-zero simulations with ACCESS-ESM-1.5 [2,3,4].

First, we focus on Europe, where heat extremes have disproportionally increased in the recent past, and characterise these extremes in long-term net-zero stabilised climates. We find that the intensities and frequencies of heat extremes remain elevated for centuries in all European regions, with significant increases for short emission cessation delays [2].

Second, we analyse the time evolution, area and population exposure to detectability of large-scale, regional and local post-net-zero changes, as well as delays in emissions cessation. Although local and extreme changes are harder to detect, changes in hemispheric and global temperatures, as well as large-scale indices, are detectable within a few centuries under net-zero emissions and for emissions cessation delays.

Finally, we argue that multi-model millennial-length net-zero Earth system model simulations are needed for a robust depiction of long-term changes and should be considered for the upcoming IPCC 7th Assessment Report [4].

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[2] Alastrué de Asenjo, E., King, A. D., & Ziehn, T. (2025). European heat extremes under net-zero emissions. *ERL*, 20(7), 074029. <https://doi.org/10.1088/1748-9326/addee4>

[3] King, A. D., Alastrué de Asenjo, E., Maycock, A., Ziehn, T., Borowiak, A. R., Clark, S., Maher, N. (in review). Detectability of post-net zero climate changes and the effects of delay in emissions cessation. <https://doi.org/10.22541/au.173930365.54563852/v1>

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Earth system responses to pathways that avoid temperature overshoots through stratospheric aerosol injections

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Abstract

Without radical reductions in the anthropogenic CO₂ emission rate, achieving the Paris Agreement climate target would imply a temperature overshoot pathway. Here, we assess key climatic consequences of avoiding temperature overshoots through deployment of stratospheric aerosol injection (SAI) in the fully interactive Norwegian Earth System Model (NorESM). In our idealised experiments with increasing CO₂ emissions (cumulatively 2000 Pg C) followed by smooth transition into negative (cumulatively -500 Pg C) and finally toward zero emissions, the model simulates a global mean temperature overshoot of approximately 0.5 degree C before temperature stabilises between 1.5-2 degree C warming relative to the preindustrial state, consistent with NorESM's TCRE (Transient Climate Response to cumulative CO₂ Emissions). We show that tropical sulphur injections into the stratosphere can be applied to shave off this temperature overshoot, comparable with a stabilisation temperature pathway in a non-overshoot reference scenario (with cumulative CO₂ emissions of 1500 Pg C). We investigate the consequences of applying SAI for the regional surface temperature evolution, and the Zero Emissions Commitment (ZEC) as well as for long-term climate stabilisation. The implications of overshooting climate targets on the long-term response of global carbon cycle will be elucidated. Finally, the long-term legacy of anthropogenic climate change associated with slow climate processes such as ocean circulation and permafrost will be investigated.

Long term overshoot and (ir)reversibility in two emissions-driven Earth System Models

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Abstract

Future climate scenario projections with Earth System Models (ESMs) are usually run with prescribed atmospheric CO₂ concentrations and only until 2100. Here we use large ensembles of two CMIP6 ESMs, NorESM2-LM and MPI-ESM1.2-LR, run until 2300 and with prescribed emissions of CO₂. We run three scenarios, two of which (SSP1-1.9 and SSP5-3.4-over) are overshoot scenarios, and determine the long-term carbon cycle and other Earth System implications of overshoot.

We find qualitatively different behaviour in the two ESMs. In MPI-ESM1.2-LR, a return to net zero CO₂ emissions around 2150 after a period of net negative emissions is sufficient to stabilise long-term global mean surface air temperature (GSAT) in both SSP1-1.9 and SSP5-3.4-over, but there is substantial residual warming in NorESM2-LM after 2150, which is related to the slow response of the Southern Ocean to forcing in this model. We find that the Atlantic Meridional Overturning Circulation (AMOC) strength closely follows GSAT in MPI-ESM1.2-LR but lags warming by around 50 years in NorESM2-LM. Global and spatial precipitation patterns are not immediately reversible, with a sustained increase in precipitation and northward shift in the intertropical convergence zone (ITCZ) for the pre- and post-overshoot periods at the same global warming level.

Both ESMs successfully remove CO₂ from the atmosphere during the negative emissions phase in SSP1-1.9 and SSP5-3.4-over, but the biosphere and ocean switch from being a carbon sink to a small carbon source after 2100 in both models and scenarios. Furthermore, the spatial distribution of carbon uptake in the land surface is heterogenous, with the boreal and tropical forests continuing to take up carbon during the negative emissions phase.

We therefore show that there is a possibility that some climate responses, including GSAT change and AMOC, are not immediately reversible following an overshoot. Running CMIP6-era models and scenarios with CO₂ emissions is a useful precursor for the upcoming CMIP7 round, for which there is an increased focus on CO₂-emissions driven runs and long term extensions, and the availability of results from several ESMs will improve confidence in climate projections in a post-overshoot world.

Hysteresis and reversibility of agroecological droughts in response to carbon dioxide removal

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Abstract

Emission reductions alone could be insufficient to limit global warming well below 1.5°C or 2°C. Consequently, the deployment of large-scale CDR technology to remove CO₂ from the atmosphere is recognized as an inevitable means of mitigating climate change. Agroecological drought is one of the most serious and widespread climate extremes that greatly threatens natural ecosystem, agriculture, energy, human health, and economies. There is a high confidence that human-induced CO₂ emissions have increased agroecological droughts in many regions. However, how increasing agroecological drought will respond to CDR is largely unknown, which hinders the recognition of and adaptation to potential associated impacts.

Here, we investigate this question by utilizing an idealized CO₂ emission and removal experiment from the CDR Model Intercomparison Project, involving eight Earth system models, and develop a new methodology to quantify climate hysteresis and reversibility. We find that drought increases in hotspot regions cannot be symmetrically reversed by an equivalent CDR: Drought severity under the CDR pathway is 65% ± 30% greater than under the emission pathway; Drought frequency increases are only partially reversed by 73% ± 18% when CO₂ emissions are balanced by equivalent CDR. Drought hysteresis and irreversibility are most pronounced in Mediterranean, Northern Central America, Northern South America, South American Monsoon, West and East Southern Africa, and Southern Australia. Our findings imply irreversible drought impacts associated with CDR, highlighting the need for planning long-term drought adaptations.

Response of the Earth system to the RESCUE overshoot scenarios: insights from OSCAR model

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Abstract

Overshoot scenarios, in which global temperatures and greenhouse gas (GHG) concentrations temporarily surpass climate targets, outline potential pathways to mitigate climate change through the eventual deployment of large-scale carbon dioxide removal (CDR) technologies. These scenarios enable exploring the reversibility of climate change impacts, the resilience of natural and human systems to short-term exceedance, and the long-term behavior of the broader climate system [1].

In this context, the Response of the Earth System to overshoot, Climate neUtrality and negative Emissions (RESCUE) project provides an extensive set of future emissions scenarios that extend beyond 2100 and include varying levels of temperature overshoot. These include pathways that aim to return global warming below 1.0 °C, 1.5 °C, or 2.0 °C targets following temporary exceedance, using different strategies for emissions reductions and CDR deployment by including ocean alkalinity enhancement (OAE), bioenergy and carbon capture and storage, afforestation and reforestation, and direct air capture [2].

To explore the response of the Earth system to these emission scenarios, we use the OSCAR (v3.3) reduced-complexity Earth system model to simulate the evolution of atmospheric GHG concentrations, radiative forcing, and global mean temperature from 1750 to 2300 [3]. The model performs simulations in the emission-driven mode using the GHG emissions and land-use forcing data provided by RESCUE.

Our simulations show that many RESCUE scenarios lead to significant overshoots in temperature, exceeding 2.5 to 3.0 °C in high-overshoot cases, before declining in response to negative emissions. Corresponding peaks are seen in atmospheric CO₂ (approaching or exceeding 700 ppm), CH₄, and N₂O concentrations. The decline in both temperature and GHG concentrations is slow and path-dependent, highlighting the inertia of the Earth system and the long timescales involved in reversing climate change. Moreover, we are exploring trends in carbon stocks, such as ocean acidification, vegetation and soil carbon, and permafrost carbon emissions, to better understand their contribution to this inertia. These results underline the importance of minimizing overshoot in both magnitude and duration to reduce long-term climate risks.

[1]. Schleussner, CF., Ganti, G., Lejeune, Q. et al. Overconfidence in climate overshoot. *Nature* 634, 366-373 (2024).

[2]. Hoersch, J. et al. Forcing datasets for earth system models of emissions-driven temperature stabilization and overshoot scenarios including multiple carbon dioxide removal methods. In preparation (2025).

[3]. Gasser, T. et al. Historical CO₂ emissions from land use and land cover change and their uncertainty. *Biogeosciences* 17, 4075-4101 (2020).

Identifying changes in the El Niño-Southern Oscillation under net zero emissions

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Abstract

The El Niño-Southern Oscillation (ENSO) is the primary mode of climate variability on interannual scales across the globe. ENSO has large effects on the global mean temperature and regional climates around the world. It is critical that we understand how ENSO and its relationships with regional temperature and rainfall may change under different net zero futures. There is some limited evidence suggesting that there may be a reduction in ENSO amplitude under net zero emissions relative to the current rapidly-warming climate, but this has been focused on very few model simulations and one specific measure of ENSO, the Niño-3.4 index. Since ENSO is an atmosphere-ocean phenomenon, and given challenges with measuring variability and its changes, we examine different atmospheric and oceanic measures of ENSO to build a more complete picture of changes in ENSO indices. We use the 1000-year long ACCESS-ESM-1.5 net zero simulations and the Zero Emissions Commitment Model Intercomparison Project (ZECMIP) to investigate ENSO changes. We also investigate changing atmospheric and oceanic processes in the Pacific Ocean under net zero scenarios and compare with 21st century warming climates. This work will help inform our overall understanding of changing climate variability post-net zero.

Long(er) term changes in the climate and carbon cycle following a temperature overshoot

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Abstract

Temperature overshoots can have significant and long-lasting impacts on our ecosystems and the services they provide. However, implications are often assessed on shorter timescales including the ramp up and ramp down phase, with fewer studies focussing on the longer-term effects after the ramp down. This is partly due to a lack of available model simulations providing data on those longer time scales.

Here we analyse the 40-member large ensemble of the CMIP6 future scenarios SSP1-2.6 and SSP5-3.4-OS including their extensions until 2300 as provided by the Australian Earth System Model - ACCESS-ESM1.5. We investigate key climate and carbon variables and how they change, particularly over the last 200 years of the simulations following the overshoot when the climate system starts to stabilise again. Focus will also be on regional changes and differences between Northern and Southern Hemisphere. We will contrast those results with additional available idealised net-zero CO₂ simulations at similar temperature levels where the transition to net-zero is realised without a temperature overshoot. This will help to provide a better understanding of the impact of overshoots on the long-term climate and carbon cycle.

Responses of spatial climate emulators to climate overshoots

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Abstract

While Earth system models (ESMs) are crucial to project future climate change, their computational cost hinders their application to explore large numbers of scenarios and to link to other modelling frameworks. Climate emulators tackle these challenges thanks to a simplified modelling calibrated on the ESMs. However, these the simplifications used for spatial emulation may not be suited for climate overshoots. Here, we use emulations conducted under the modelling initiative FASTMIP to compare and analyze the behaviors of the spatial emulators PRIME, MESMER and STITCHES under various overshoot scenarios. Using CMIP6 data, we identify for which ESMs and variables the responses of the emulators differ from the ESMs, thus the limits of their emulation techniques. We suggest approaches to improve the modelling of overshoots in spatial climate emulators. A more robust representation of overshoots by climate emulators is crucial for more reliable projections, which matters to assess the implications of climate overshoots. We advocate that modelling teams of climate emulators improve the capacity of their emulator to handle overshoots, and we recommend caution to the communities using projections from spatial climate emulators on overshoot scenarios. Finally, the next phase of FASTMIP is outlined, in particular with a new generation of scenarios and a broader range of spatial climate emulators.

Marine carbon sink dominated by biological pump after temperature overshoot

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Abstract

In the event of insufficient mitigation efforts, net-negative CO₂ emissions may be required to return to acceptable limits of climate warming as defined by the Paris Agreement. The ocean is an important carbon sink, mostly driven by physico-chemical carbon-uptake under increasing atmospheric CO₂ levels. Yet, the processes governing this carbon sink under net-zero or even net-negative CO₂-emission regimes are unclear. Here we assessed changes in marine CO₂ uptake and storage mechanisms under a range of idealized temperature overshoot scenarios in an Earth System model of intermediate complexity over centennial timescales. We show that while the fate of CO₂ from physical-chemical uptake was very sensitive to future atmospheric boundary conditions and CO₂ was partly lost from the ocean at times of net-negative CO₂-emissions, storage associated with the biological carbon pump continued to increase and may even dominate marine excess CO₂ storage on multi-centennial time scales. Our findings imply that excess carbon attributable to the biological carbon pump needs to be considered carefully when quantifying and projecting changes of the marine carbon sink.

Simple Climate Models can agree on everything but the carbon sink.

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Abstract

While complex models of the Earth system are increasingly able to represent processes within the carbon cycle that determine Earth's land and ocean carbon sinks, a variety of approaches exist to simplify the representation of these systems in reduced-complexity models, or simple climate models (SCMs). SCMs can be used as tools for conceptual understanding and for applied decision-making in climate mitigation policy assessment. We compare four SCMs with varying carbon cycle structures and find consistent representation of idealized and historical global mean temperature (GMT) in increasing-emissions scenarios, but inconsistencies in how GMT evolves in idealized decarbonization scenarios. We assess differences in how carbon is allocated when emissions increase and find that differences in carbon cycle structure can lead to differences in how carbon is removed from the atmosphere, leading to differences in implied residence times, implied non-carbon cycle parameter values, and importantly, the resulting values of critical climate metrics, including TCRE and ZEC. SCMs' carbon cycle representation spans a range of structural diversity that allows for many ways to be simple and consequently many ways to realize the observed climate response to emissions, but this diversity exists as an unrecognized and unpropagated source of uncertainty, as it is currently not well represented in existing calibrated ensembles. This missing structural carbon cycle uncertainty heralds the need for process-driven constraints on carbon sink behavior both from Earth System Models or observations but also reflects an existing knowledge gap related to the biogeochemical response to emissions, including the implicit timescales and feedbacks within that response. We believe this work raises important epistemological discussions related to SCMs as tools for understanding, including (1) how to interpret projections with increasingly unwieldy uncertainty (2) how SCMs can continue to serve as tools in decision-making and conceptual understanding while also serving to identify critical research gaps in this way. These issues and discussions will become increasingly important as climate modelers and decision-makers continue to explore decarbonization and post-net-zero emissions landscapes.

Regional cooling of heat extremes in a net-zero world

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Abstract

This study exploits the idealised climate projections produced by the UK Earth System Model 1.2 under the Tipping Point Modelling Intercomparison Project (TIPMIP) protocol to explore changes in climate extremes in response to net-zero and net-negative emissions. Stabilised warming levels (SWL) ranging from +1.5°C to +5°C are compared to analyse the effects of delayed achievement of net zero emissions. Net-negative emissions are designed to simulate anthropogenic CO₂ removal from the atmosphere. In this work, we focus on global temperature extremes and their evolution through the stabilised and negative emission runs. We find that the Northern Hemisphere summer daily maximum temperatures show a general cooling trend in the +3°C, +4°C and +5°C SWL projections opposed to a strong warming occurring in the Southern Hemisphere, especially in the Southern Ocean. The NH cooling trend is not spatially homogenous, but cooling hotspots are concentrated across the 45-65°N zonal band. Here, the highest cooling trend is registered for the upper tail of the annual temperature distribution, with temperatures on the warmest day of the year (TXx) and the warmest 5-day period (TX5x) decreasing by up to 1.8°C per century.

The dynamical and thermodynamical contributions to this regional cooling trend are explored using data on surface heat fluxes and by constructing circulation analogues. The analysis shows how regions experiencing a decreasing trend in yearly extreme temperatures have a corresponding increase in summer latent heat flux. Consistently, a significant cooling trend persists when TXx and TX5x events with analogous dynamical patterns from the first and last 50 years of the simulation are compared, suggesting that some cooling occurs independent from the dynamical forcing. It results that changes in surface heat fluxes alone account for more than one third of the total projected cooling trend and can decrease regional temperature extremes by 2-4°C relative to the global mean on centennial timescales. We reconcile the projected cooling trend with evidence on the latitudinal expansion of forests at the expenses of grasslands and the concomitant replacement of needleleaf vegetation with broadleaf. These biome shifts lead to a local increase in albedo and plant transpiration, both contributing to the cooling trend. The same thermodynamic changes occur to a lower extent in the negative emission runs. This is mainly due to the cooling effect on global mean temperatures caused by the decreasing CO₂ concentration that does not allow the same latitudinal expansion of broadleaved vegetation. At the same time, the analysis of the circulation analogues also shows a weakening trend of the high-pressure systems associated with the temperature extremes suggesting a complementary cooling influence from changing atmospheric circulation. As a result, a similar cooling trend in the annual heat extremes is projected regionally in the stabilised (-1.8°C/century) and negative (-2.5°C/century) emission runs despite global mean temperature trends having opposite sign (+0.3°C/century and -0.8°C/century).

Differences in CDR representation between Integrated Assessment Models and Earth System Models

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Abstract

According to the Working Group III of the IPCC, carbon dioxide removal (CDR) from the atmosphere is considered ‘unavoidable’ to counterbalance hard-to-abate residual emissions and reach the climate target set by the Paris Agreement (IPCC, 2022). At present, sufficient mitigation policies are lacking and a temporary or permanent temperature overshoot of the 1.5°C target is expected in the second half of the century.

As part of the RESCUE project, we used the fully coupled earth system model CMCC-ESM2 to simulate a realistic portfolio of land- and ocean-based CDR approaches, namely afforestation / reforestation, BECCS, DACCS and ocean alkalinity enhancement. These simulations explored scenarios both with and without temperature overshoot of different magnitudes across two carbon budget pathways.

Two key aims of this project are to (a) assess the (ir)reversibility of earth system feedbacks, and (b) compare the representation of CDR options between the Integrated Assessment Models (IAM), which lack many dynamical earth system feedbacks, and the Earth System Models (ESM), which do not account for explicit socio-economic pulses driven, e.g., by technological advancement. Indeed, a temperature / carbon budget target that is achieved in the IAMs may not be met by ESMs.

In this framework, the CMCC-ESM2 model was used to simulate the effect of prescribed CDR negative CO₂ emissions as produced by the IAM and, by contrast, the carbon removed through the deterministic simulation of different CDR techniques within the ESM.

Furthermore, two additional simulations are run: a no-CDR emission-driven simulation, which is used as counterfactual to quantify the overall removal of the CDR portfolio, and a simulation with imposed atmospheric CO₂ trajectory from the fully coupled CDR scenario. The difference between the two serves to determine the earth system feedbacks (though excluding the biophysical feedbacks).

The simulation protocol setup in the project allows us to compare the outcomes of the different representations of CDRs in IAMs and ESMs and, more specifically, to investigate the differences in cumulative carbon budget targets and realised temperatures between the IAMs and the ESMs. Furthermore, we evaluate the possible causes and implications of disagreements between the two modelling frameworks for the assessment of the Earth System feedbacks reversibility under different overshoot pathways.

This project has received funding from the European Union’s Horizon Europe research and innovation programme under grant agreement no. 101056939 (RESCUE)

Long-run emulator calibration increases warming and sea-level rise projections

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Abstract

Physically-based climate emulators have emerged as a key line of evidence to assess global mean surface temperature (GMST) and sea-level rise (SLR) projections from diverse emissions scenarios. Many climate emulators use a two- or three-layer energy balance model (EBM) to project GMST and SLR from a time series of radiative forcing. The EBM is often calibrated on 150 year-long abrupt-4xCO₂ experiments in Earth System Models (ESMs), since the constant forcing boundary condition allows the parameters of the EBM to be estimated using (for example) maximum likelihood estimators. However, the climate has not reached equilibrium after 150 years of forcing, and the long-term response is governed by the characteristic timescale of the deep ocean response which may be of the order of 1000 years. Therefore, it is difficult to estimate the long-term climate response of ESMs from only 150 years of calibration data. As emissions scenarios are being run for at least 250 years (1850–2100) and ideally 450 years (1850–2300) or more, this could pose a problem for adequately emulating long-term climate responses.

Here, we use abrupt-4xCO₂ data from 13 ESMs participating in longRunMIP to calibrate a three-layer energy balance model for successively longer periods. The models provided between 900 and 5900 years of output data to abrupt-4xCO₂, and we focus our headline analysis on the 900-year timeframe. Firstly, we show that using the first 900 years of data for calibration almost always results in a better fit of the EBM to the long-term 4xCO₂ trend over the full period than the 150-year calibration, showing that the 900-year calibration better captures the long term trend. Secondly, the equilibrium climate sensitivity from the 900-year calibrations is almost always higher than in the 150-year calibrations, showing that long-term warming is systematically underestimated using a 150-year calibration.

When applying scenario forcing data to EBMs calibrated on 900 years of output, we find similar historical warming profiles to the 150-year calibrations in the same models, but 21st century warming projections tend to be higher for the 900-year calibrations across all SSP-RCP combinations. Focusing on the overshoot scenarios SSP1-1.9 and SSP5-3.4-over, we find that in the ensemble median, GMST anomalies in 2500 are similar between the 150- and 900-year calibrations, but the additional time spent in overshoot contributes towards higher levels of thermosteric SLR in all 13 models and for all scenarios (including overshoot scenarios). Therefore, peak warming and long-term sea-level rise are both underestimated by not using sufficiently long calibration data for EBMs, and further reinforces the critical need to limit peak warming to as low a level as possible. CMIP7 includes a recommendation to run abrupt-4xCO₂ experiments for 300 years. However, we find that 300 years of calibration data offers only a small difference relative to 150 years. Therefore, we recommend running abrupt-4xCO₂ experiments for time periods beyond 300 years, ideally for 1000 years, in order to provide adequate calibration data for climate emulators.

Diagnosing Warming-Induced Emissions Greenhouse Gas Feedbacks Under Climate Overshoot (WIE-MIP)

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Abstract

Warming-induced greenhouse gas emissions (WIE) from thawing permafrost, wetlands, wildfires, soils, and other Earth system processes appear to be emerging in the recent acceleration in the growth of atmospheric CO₂, CH₄ and N₂O concentrations. Concerns that warming would lead to an increase in indirect emissions from natural systems were raised almost 50 years ago, and these emissions remain a blind spot in climate science and policy. While a range of estimates exist in the literature for future WIE emissions, these estimates remain poorly understood in the context of new-policy relevant emissions scenarios and affect our quantification of the remaining carbon budget to avoid additional warming as well as the state of the Earth system when net-zero emissions are reached. The Warming-Induced Emissions Model Intercomparison (WIE-MIP) was recently established to close this science and policy gap by developing a new protocol and set of climate scenarios to constrain WIE temperature feedbacks, WIE characteristics under climate overshoot, and emissions under unmitigated scenario using climate emulators. WIE-MIP brings together a diverse set of land-surface models to explore individual WIE emissions as well as interactions between WIE processes. Outputs from WIE-MIP will be used to evaluate the remaining carbon budget, reversibility under climate overshoot, and implications for the zero-emissions commitment. WIE-MIP is fast tracked to support IPCC AR7 timeline for publications and to explore opportunities for integration with greenhouse gas inventories.

Theme 4: Climate impact (ir)reversibility

Chair: Debra Roberts, Edward Byers

Achieving global temperature decline after overshoot does not guarantee the reversal of local climate impacts. To further complicate the picture for policy-makers and practitioners, regional climate patterns will continue to change even under global temperature stabilization as Earth System components keep adjusting and equilibrating. Vulnerabilities and exposure dynamics in human and natural communities may differ substantially before and after overshoot, and will be affected by the extent and length of overshoot. This session tries to advance our understanding of key questions such as how a world after overshoot is different from a world without it, and for whom? What are the benefits of long-term global warming reversal compared to stabilisation at peak warming? Specific focus will be given to understanding irreversible impacts on human timescales, i.e. in oceans, the bio- and cryosphere, and the already at risk ecosystems. Beyond changing climate hazards, the temporal interrelations of overshoot pathways.



Episode 5: Climate impact (ir)reversibility with Debra Roberts

Overshoot, Irreversibility, and the Social Cost of Greenhouse Gases

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Abstract

As global climate policy increasingly confronts the likelihood of overshooting the 1.5°C target, understanding the economic implications becomes critical for designing effective pricing and mitigation strategies. This study analyses how overshoot magnitude and damage irreversibility affect the social costs of carbon dioxide (SCC), methane (SCM), and contrails (SC-contrail). Here, social cost refers to the net present value of climate damages per ton gas emitted, and per unit of efficacy-adjusted energy forcing for contrails.

Using a modified version of the integrated assessment model DICE ([Hänsel et al., 2020](#); [Azar et al., 2023](#)), we simulate two overshoot pathways, with peak warming levels of 1.6°C and 1.8°C, followed by a return to 1.5°C by 2100 and beyond. Damages are assessed over a 500-year horizon to capture long-term impacts.

We estimate social costs in 2020 and 2050 under two contrasting assumptions about damage reversibility: one using the preferred damage function of [Howard & Sterner \(2017\)](#), assuming full reversibility; and another using the same function but assuming partial irreversibility, where 50% of damages persist after temperatures decline, a crude assumption intended to illustrate the potential implications of damage irreversibility.

Our preliminary findings are:

- Under fully reversible damages, a higher level of overshoot increases SCC, SCM, and SC-contrail in both 2020 and 2050. However, the effect is relatively small—less than 10% for all three forcings in both 2020 and 2050.
- Damage irreversibility raises the social cost of all forcings, particularly short-lived ones like CH₄ and contrails, by making damages more persistent than in the reversible case. The impact on SCC is smaller than for SCM and SC-contrail since the temperature impact of CO₂ emissions is largely irreversible in itself.
- For both temperature pathways, damage irreversibility increases the social cost of CH₄ and contrails in 2020 by 20–35% and around 15%, respectively, compared to the reversible case. In contrast, the social cost of CO₂ in 2020 increases by less than 5%.
- In 2050, damage irreversibility increases the social cost of CH₄ and contrails by several hundred percent in both pathways, compared to the reversible case, whereas the cost of CO₂ increases by about 10%.
- The strong impact of irreversibility on the social cost of short-lived forcings in 2050 depends on the timing of the emissions pulse, the short-lived nature of their temperature effects, and how these align with the timing of peak warming in the overshoot pathways. This timing sensitivity is much less pronounced for SCC, which is more influenced by long-term, post-overshoot climate impacts due to the persistent warming effects of CO₂ emissions.

These results highlight two key takeaways. First, overshoot and irreversibility are important to incorporate into social cost estimates, underscoring the need for further research on damage reversibility. Second, the social cost of short-lived forcers such as CH₄ and contrails is more sensitive to irreversibility than that of CO₂. Consequently, ratios like SCM/SCC and SC-contrail/SCC could serve as emission metrics, offering insights beyond the Global Warming Potential (GWP) approach, which ignores aspects related timing, overshoot and irreversibility.

Title: Assessing the (Ir)reversibility of Climate Change Impacts in Southern Africa

Malon Muronzi

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Abstract

Title: Assessing the (Ir)reversibility of Climate Change Impacts in Southern Africa

Background:

Southern Africa is highly vulnerable to climate change, with observed impacts including increased frequency and intensity of droughts, floods, and extreme weather events. Understanding the potential reversibility or irreversibility of these impacts is crucial for informing adaptation strategies and policies.

Objective:

This study aims to assess the reversibility and irreversibility of climate change impacts in Southern Africa, focusing on key sectors such as agriculture, water resources, and ecosystems.

Methods:

The study will employ a combination of climate model projections, empirical data analysis, and expert consultation to assess the extent to which climate change impacts can be reversed or mitigated through adaptation measures.

Results:

Preliminary findings suggest that some climate change impacts, such as changes in rainfall patterns and temperature extremes, may be irreversible, while others, such as soil degradation and biodiversity loss, could potentially be reversed or mitigated through targeted interventions.

Conclusion:

The (ir)reversibility of climate change impacts in Southern Africa highlights the urgency of implementing effective adaptation measures, particularly in sectors most vulnerable to irreversible changes. By better understanding the nature of climate change impacts, decision-makers can prioritize resources and efforts towards reducing vulnerability and enhancing resilience across the region.

Evolution of climate change risks in the context of 1.5°C overshoot – a conceptual framework

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Abstract

The reports of the IPCC's sixth assessment cycle made clear that changes in climate extremes and climate-related risks increase with every increment of warming, and that risks will be greater if global warming rises above 1.5°C than if it had been limited to or below that level. Extreme heat and heavy precipitation events, as well as droughts in some regions, are projected to become more intense and frequent with every increment of global warming. Warming beyond 1.5°C also increases the likelihood of irreversible losses such as warm-water coral reef collapse. It is expected that if warming could be reduced back to 1.5°C, this would generally limit the overall risks compared to stabilising warming at higher levels, although the risks may still be more severe than if 1.5°C had never been exceeded. However, evidence quantifying this has so far been relatively limited. Understanding the evolution of the drivers of risks and their interplay informs how these need to be accounted for in the context of adaptation, and how feasible such overshoot pathways may be in the real world. Further challenges include understanding of the contextual aspects of risks at system, sector and regional scales, and how risk may propagate among them. To help foster more systematic research into those risks, we propose a conceptual framework of how key drivers and outcomes might evolve in an overshoot world.

Emulating the Effect of Overshoots on Regional Climate: an Impulse Response Function Approach

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Abstract

Spatial climate emulators are essential tools for generating highly resolved regional climate predictions without the computational cost of Earth system models (ESMs). By enabling the exploration of a wide range of scenarios in a very short time, they play an important role in risk assessment. While various methodological frameworks exist, most emulators are based on pattern scaling: they deduce a spatial pattern from an ESM and scale it by a global warming level. Those global warming levels can be efficiently computed from a simple climate model. This linear approach performs very well for transient and acceptably well for stabilization scenarios. However, it fails to reproduce any hysteresis and irreversibility in the climate system, thus failing to capture the effects of overshoots. Here, we investigate the possibility to reproduce hysteresis by means of an impulse response function (IRF) approach. Instead of expressing local variables as a linear function of current global mean temperature (GMT), we define them by a convolution of historical GMTs (since 1850) with an IRF. This IRF, composed of a sum of exponentially decaying terms, assigns a lower weight to temperatures far in the past and more importance to recent GMT levels.

We first show how a simple IRF allows to partially emulate the hysteresis observed in the overshoot scenario SSP5-3.4 without degrading the performance on transient or stabilization scenarios. Then, based on physical considerations, we construct various enhanced IRFs which are designed to capture different types of regional post-overshoot behavior. These include hysteresis with and without reversibility, expressed through reversed, partially reversed, overcompensated and continued trends. We show how the IRF approach yields a significant improvement in the emulation of regional surface air temperature. We expect this method to be applicable to other climate variables such as soil moisture. Given the increasingly high relevance of overshoot effects for risk assessment, we propose to implement this method into spatial emulators such as MESMER. Our findings suggest that it could benefit the accuracy of their predictive power with only a marginal increase in computational cost.

Heat-mortality impacts under 1.5°C overshoot pathways

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Abstract

The risk of heat-related mortality is strongly increasing as global temperatures continue to rise. Accordingly, the additional health burden of failing to meet the 1.5°C goal of the Paris agreement poses a key concern to society and policymakers.

In this study we assess the change in heat-related mortality when overshooting the 1.5°C target by combining climate model output with a well-established epidemiological model to estimate future heat-mortality impacts. We use data from ten climate models representing more than 100 model runs that follow the SSP1-19 pathway. Additionally, we use a 100-member single model initial condition large ensemble (SMILE) to estimate the heat-mortality impacts at different stylized temperature stabilization scenarios. Combined, these simulations allow us to explore the health impacts of different pathways that vary in their peak warming and duration of overshoot.

The epidemiological analysis relies on quasi-Poisson regression time series analyses and requires daily city-level mortality data. We access mortality data for more than 1000 locations through the MCC (Multi-Country Multi-City) Collaborative Research Network database to establish location specific temperature-mortality relationships. These relationships are then combined with the bias-corrected daily mean temperature data from the climate models to calculate future estimates of heat-mortality.

This modelling set-up allows us to estimate peaks in heat-mortality and to identify geographical patterns arising either from different regional warming trends or from location specific vulnerability to heat. In quantifying the heat-mortality burden of overshoot pathways, it provides an empirical insight into the implications of failing to meet the 1.5°C temperature goal of the Paris Agreement. These findings may facilitate legal and policy scrutiny of emission reduction pathways consistent with different warming outcomes.

Threshold Breaching and Tipping Points in Impacts

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Abstract

As the world faces increasing likelihood of exceeding the 1.5°C warming threshold, understanding how climate overshoot translates into irreversible impacts across socioecological systems becomes critical. This research examines threshold breaching and tipping points in human and ecological systems, with particular focus on the (ir)reversibility of climate impacts and overshoot legacy effects.

We present a comprehensive typology of climate-socioecological system interactions, distinguishing four pathways: cascade effects where physical tipping points trigger socioecological tipping cascades (Category A); propagation pathways where physical tipping points cause severe impacts that systems absorb without transitioning to new states (Category B); threshold effects where gradual climate change drives socioecological systems across critical thresholds (Category C); and incremental responses following conventional impact scaling (Category D).

Our analysis focuses on five core socioecological systems affected by climate and biophysical transmission pathways: food systems, built environment, health, displacement, and economy. Each system operates within broader contextual dimensions: including access to resources, governance structures, inequality levels, and development status, that both determine vulnerability and evolve in response to accumulating impacts.

Critical findings reveal substantial variation in the (ir)reversibility characteristics across systems. In food systems, we identify potential cascading failures from ecosystem tipping points, including marine and terrestrial system collapses that disrupt provisioning services. For the built environment, infrastructure thresholds demonstrate how overshoot scenarios can push urban systems beyond limits to adaptation, rendering conventional planning approaches inadequate. Health impacts exhibit clear physiological thresholds, particularly regarding heat survivability limits and worker productivity thresholds that become effectively irreversible once regional climates exceed these boundaries.

The research highlights how overshoot fundamentally alter the temporal dynamics of irreversibility. Whilst some impacts may appear reversible if temperatures decline post-overshoot, the analysis reveals how threshold effects create legacy impacts that persist beyond the duration of overshoot itself. Economic disruptions, displacement patterns, and health system collapses demonstrate particular resistance to reversal, even following temperature stabilisation.

Crucially, we examine how differential vulnerability and limited adaptive capacity create conditions where identical climate changes produce vastly different outcomes across

populations. Communities facing poverty, marginalisation, or high baseline exposure demonstrate heightened susceptibility to irreversible threshold breaching, suggesting that overshoot scenarios will exacerbate existing inequalities in irreversible ways.

Our analysis contributes to understanding overshoot legacy effects by demonstrating how climate system tipping points propagate through transmission pathways to create irreversible socioecological consequences that persist beyond the climate overshoot period itself. These insights are essential for developing realistic post-overshoot adaptation strategies and assessing the true costs of allowing temporary temperature exceedances.

This work forms a chapter in the World Climate Research Programme's (WCRP) assessment of high-impact climate events and tipping points.

Do Environmental Sustainability Practices Shape Economic Performance in a Warming World? Empirical evidence through dynamic models.

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Abstract

Climate change has become a central factor influencing the economic performance of countries. Climate shocks, such as rising temperatures, increased rainfall, and extreme precipitation—pose significant threats to macroeconomic stability by undermining economic productivity, human health, and ecosystem resilience, as highlighted in the latest IPCC report. However, environmental sustainability can play a vital role in mitigating these adverse effects. To empirically examine this relationship, this study investigates the moderating role of environmental sustainability practices in shaping economic performance by offsetting the impacts of climate shocks, specifically those related to temperature, precipitation, and rainfall. Using data from 96 countries over the period 1995-2022, we apply both static and dynamic panel models. The Environmental Sustainability Index (ESI), which captures multiple dimensions of sustainability practices, is used to assess its moderating role in the climate-economy nexus. For robustness, we also use the ND-GAIN index, an indicator of climate vulnerability to group countries into high and low vulnerability categories. Our results show that rising temperatures significantly reduce economic performance, particularly in countries with inactive environmental sustainability measures. However, the effects of precipitation and rainfall on economic performance remain inconclusive. Overall, the findings underscore that the effectiveness of sustainability practices in moderating climate impacts depends on the degree to which they are adopted. These results suggest that policymakers should prioritize the integration of comprehensive environmental sustainability strategies to enhance economic resilience in tackling the climate crisis.

Humanitarian impacts of temporary climate overshoot: Irreversibility and little relief

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Abstract

It is increasingly likely that global warming will exceed the 1.5°C warming threshold of the Paris Agreement. A scenario in which temperatures first exceed a threshold, -such as 1.5°C- and thereafter decline below this threshold again is called temporary climate overshoot; in-short overshoot. Overshoot comes with unique challenges, impacts and risks. While temperature changes may be reversible, other changes in the earth system as well as climate impacts will be irreversible or may continue for centuries. Thus, we cannot expect the world to “return to normal”, but rather we need to prepare for new realities, which may include new risks and impacts. Whilst earlier assessments, such as the IPCC’s 6th Assessment Report, have engaged with the impacts of temporary climate overshoot, substantial knowledge gaps remain, in particular for cascading impacts and impacts dynamics under cooling. This work aims to address this gap, with a focus on humanitarian impacts, the extent to which these differ across regions, and the resulting needs for the humanitarian system. We do so by combining literature review and expert workshops from climate sciences and the humanitarian system into overshoot risk narratives.

Our research confirms that while temperatures may decrease when greenhouse gas emissions would decline, temporary climate overshoot can result in irreversible, time-lagged impacts, as well as climate changes that are reversible. Examples of irreversible impacts are global sea level rise, saltwater intrusion, glacial retreat or loss of biodiversity. These cannot be reversed in timeframes relevant to humans, and have implications on the volume and location of humanitarian needs. For example, impacts from sea level rise will include increased severity of storm surges, increased flooding, and displacement in coastal settlements resulting in more humanitarian needs along coasts. Salt water intrusion will reduce agricultural yields increasing food insecurity. And glacial retreat will create water insecurity from glacial fed rivers, leading to droughts, with subsequent humanitarian impacts even as temperatures decline. Possible reversible climate effects under temporary climate overshoot include a reduction in surface air temperature (particularly in the Northern latitudes), and a reduction in extreme precipitation. However, reversible climate effects will also have their own unique challenges for the humanitarian system. For example, health impacts may arise from changes in the variability of vector-related diseases during a cooling phase. Agricultural practices that have adapted to warmer conditions may have to change again, impacting yields and food security. Effectively, many of the systems that society rely on will have to adapt to warming, and then re-adapt to cooling.

To address these challenges, we recommend: i) Cautioning against narratives that present overshoot as a ‘safe’ scenario in which impacts will reverse. ii) Prioritizing regional systemic risk assessments to tailor responses. iii) Acknowledging (ir)reversible impacts in planning and policy. iv) Preparing for long-term adaptation using flexible approaches like adaptation pathways. v) Conceptualising overshoot and reversibility, considering timelines relevant for

adaptation and humanitarian needs. vi) Rethinking humanitarian strategies for a world affected by temporary climate overshoot, where actions today define the resilience of future societies.

Irreversible risks to biodiversity after a 2°C temperature overshoot

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Abstract

Temperature overshoot scenarios are becoming increasingly relevant as global emissions mitigation efforts lag behind climate targets. However, the extent to which cooling the planet can reverse climate risks to biodiversity remains unclear. We assessed the reversibility of biodiversity risk from temporarily exceeding 2°C global warming by quantifying the dynamics of exposure and de-exposure to potentially unsafe temperatures for 37,678 terrestrial and marine vertebrate species using a high temperature overshoot scenario.

For every 0.1°C of warming beyond 2°C, the number of species at high risk from thermal exposure increases by 8%. In contrast, for every 0.1°C decrease in temperature after the peak, the relative decrease in species at risk is only 4%. This asymmetry occurs because de-exposure often requires an additional global temperature drop of 0.15°C (land) and 0.25°C (ocean) compared to exposure levels, resulting in 29% more species at risk after the return to 2°C compared to stabilization at 2°C without overshoot.

Amphibians and reptiles show the highest proportion of species at risk, with 30% and 38% of all amphibians analyzed at risk at 2°C before and after peak, respectively, and 27% and 33% of reptiles analyzed at risk at 2°C before and after peak. Species at high risk are predominantly found on islands and are currently threatened by other anthropogenic stressors such as habitat loss and degradation, pollution, and invasive species.

Our findings underscore the urgent need for rapid climate action to prevent overshoot and minimize irreversible biodiversity impacts.

Studying the mitigation and adaptation nexus under the risk of climate tipping

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Abstract

There is increasing evidence that with advancing climate change, tipping points may be crossed that lead to regime-shifts in climate patterns with consequences for the scope to counteract climate change by mitigation or responding to climate change by adaptation. In contrast to mere "shocks", such regime changes lead to a reconfiguration of climate or economic dynamics, changes in the relevance and interaction of systems states, and possible changes in the objective function or constraints. They are typically considered to be irreversible or very difficult to reverse. Examples include sea-ice or ice-shield meltdown, reversal of the Gulf Stream, or switching from carbon sinks to carbon sources as in case of the demise of rain forests or swampland, the thawing of permafrost soil [1]. The study of such regime switches is technically involved, in particular the representation of adaptive actions after a switch as a function of both the time of switch and the duration since the switch, as well as the linkage between pre-switch actions (mitigation or build-up of adaptation capacity) and post-switch behaviour. We study the role of random regime switches, depending on an endogenous climate-state dependent hazard rate of tipping, within a DICE-style model in which a planner trades off emission abatement, adaptation capacity investment, saving and consumption to maximise intertemporal welfare. Specifically, we build the analytical framework on a recent approach by [2] that employs an age-structured optimal control approach for the solution and numerical representation of optimal control problems with stochastic regime-switch. We study mitigation, adaptation capacity investment and savings patterns under the expectation of tipping (Gulf stream reversal, increased natural disaster risk, ...) and compare them against naive settings, in which they are (partially) ignored. We also derive the social cost of carbon for the different scenarios and decompose it into its components relating to tipping risks but also the scope to adjust to them. Finally, the explicit inclusion of adaptation capacity in the system allows us to explore the trade-off between investments in mitigation (which is effective at all times) and investments in the adaptation capacity (which only becomes beneficial in case a tipping event has occurred).

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How would Overshoot Impact Freshwater Hydrology and Water Resources?

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Abstract

While overshoot risks are increasingly well recognized in global climate risk assessments, they remain relatively poorly understood in the context of regional impacts and adaptation. Risks to regional hydrology and water resources from overshoot pathways are qualitatively different from risks associated with monotonic warming trajectories, and are likely underestimated in current research and policy. While overshoot has been relatively widely described in the climate literature, the impacts of overshoot on individual system characteristics have not. We suggest that failure to consider disparities between monotonic and overshoot warming impacts on hydrology and water resources presents particular risks due to divergent adaptation needs. Processes with decadal hysteresis are especially vulnerable. These include glacial contributions to streamflow; hydrologic consequences of vegetation change; altered groundwater; higher water use for fossil fuel combustion and carbon dioxide removal; and water infrastructure and policy that depends on climate conditions. We argue that risks of overshoot cannot be fully captured in current integrated assessment models and that overshoot needs to be specifically evaluated to adequately characterize risk in the water system. We suggest some paths forward for science and policy to improve understanding of overshoot consequences using existing tools. While these approaches are promising, we also recognize that decisions must be made even without perfect abilities to model overshoot consequences, and suggest some priorities given that uncertainty.

Overshoot and Solar Radiation Modification: The Limits of Climate Engineering for a Just 1.5°C Future

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Abstract

As the window for limiting global warming to 1.5°C narrows, solar radiation modification (SRM) has emerged in global climate discourse as a potential temporary measure to reduce global temperatures while mitigation and carbon removal strategies are scaled up. The main proposed SRM approach is stratospheric aerosol injection (SAI), which aims to cool the planet by altering the Earth's radiative energy balance and offsetting part of the greenhouse gas (GHG)-driven warming. A frequently discussed theoretical application of SAI is called “peak-shaving”, where SAI is deployed alongside overshoot pathways to temporarily reduce warming and prevent global temperature from breaching critical thresholds. Existing research has typically analyzed SAI by comparing scenarios with and without intervention, often using moderate or high-emission baselines. Some studies have contrasted a stabilized SAI 1.5°C world with a transient 1.5°C scenario, an approach that has been shown to be flawed¹. However, few studies offer direct, like-for-like comparisons between a 1.5°C world stabilized through SAI and one achieved via GHG mitigation. Our study aims to fill this gap. Using simulation outputs from CESM2-WACCM, we conduct comparative analyses of 1.5°C and 2°C stabilized worlds achieved through (1) GHG mitigation (AERA-MIP²), (2) SAI deployment with a business-as-usual scenario (SSP2-4.5) as baseline (ARISE-SAI³), and (3) SAI deployment with an overshoot pathway (SSP5-3.4-over) as baseline (GeoMIP⁴). Our analytical framework allows us to provide quantitative evidence to probe the “moral hazard” dimension of SRM. We analyze a range of climatic indicators (including extremes), focusing on regional and seasonal impacts. Special attention is given to four socioeconomically vulnerable regions: South Asia, East Asia, South Central America, and West Africa. Our findings indicate that while SAI effectively reduces global mean temperatures, it introduces significant regional and seasonal disparities, especially in hydrological variables. These uneven impacts raise critical concerns about equity and accountability, highlighting the risk of creating climatic “winners” and “losers” under SRM deployment. Our results illustrate how a climate engineered future differs from stringent greenhouse gas mitigation scenarios.

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Regional climate and carbon cycle irreversibility after overshoot

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Abstract

With the current rate of climate change, overshooting the remaining global carbon budget for a warming target of 1.5 °C is virtually inevitable. While carbon dioxide removal may help return to safer temperature levels, the feasibility and risks of such overshoot scenarios depend on how the climate system responds during and after the overshoot. Here, we examine regional climate and carbon-cycle responses to emission-driven overshoot scenarios that vary in magnitude, duration, and timing. Globally, physical climate responses appear largely reversible under moderate overshoot, accounting for response lags of several decades. However, in high overshoot scenarios, some climate feedbacks and biogeochemical processes show signs of irreversibility at regional scales - potentially linked to the crossing of Earth system tipping points. These results inform about the reversibility of climate system processes under overshoot, aiding the refinement of mitigation thresholds in global climate policy.

Many reasons to safeguard the polar regions from dangerous geoengineering

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Abstract

Greenhouse gas emissions continue to drive global warming, with severe and often irreversible impacts, especially in polar regions. While deep decarbonization remains essential to meet the 2015 Paris Agreement targets, geoengineering proposals are gaining public attention as potential alternatives.

In this presentation, we focus on stratospheric aerosol injection (SAI), one of several geoengineering ideas evaluated in a review paper by a community of polar and cryosphere scientists. We evaluate SAI in terms of technological readiness, environmental risks, scalability, governance, ethical concerns, and potential for unintended consequences. Our analysis finds that SAI is neither a viable nor responsible solution in the coming decades. Pursuing such options risks diverting resources from urgent mitigation and adaptation priorities.

Authorship: Marie Cavitte, Martin Siegert, Heidi Sevestre and authors of **Safeguarding the Polar Regions from Dangerous Geoengineering: A Critical Assessment of Current Projects and Future Prospects**, published in *Frontiers in Science*. Paper is available at: <https://www.frontiersin.org/journals/science/articles/10.3389/fsci.2025.1527393/full>)

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Theme 5: Overshoot legacy and tipping elements

Chair: Jonathan Donges, Caroline Zimm

Overshoots may leave a long-lasting legacy, in particular if irreversible dynamics of Earth System tipping elements were triggered during overshoot. Furthermore, emerging insights suggest that to limit tipping risks on centennial timescales, global warming reversal to levels way below present-day may be required. Yet, the temporal dynamics of potential tipping elements under global peak and decline pathways are so far not well understood. This session welcomes contributions that shed light on dynamics of global tipping elements under peak and decline pathways. Specific focus will be put on determining long-term consequences of near-term climate (in)action up to peak warming, and the possibilities and limits of reducing long-term risks by reversing global warming. The session also welcomes contributions focusing on overshoot legacy beyond tipping elements in relation to global scale outcomes such as sea level rise and ocean dynamics.



Episode 6: Overshoot legacy and tipping elements with Jonathan Donges

Impacts of Temperature Overshoots on Climate Tipping Risks

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Abstract

The international community has agreed to limit global warming to well below 2°C, with best efforts to reach 1.5°C above pre-industrial levels by the end of this century. However, recent studies suggest that an at least temporary overshoot of this temperature target is becoming increasingly likely, with several analyses identifying the current decade as the first to fall within the critical 20-year window for exceeding 1.5°C.

Transgressing such temperature levels pose serious threats to some of the most critical parts of the Earth system—the so-called climate tipping elements—including the Greenland and West Antarctic Ice Sheets, the Atlantic Meridional Overturning Circulation, and the Amazon rainforest. This presentation will provide the latest scientific insights into how overshooting such temperature targets amplifies the risk of triggering one or multiple climate tipping points, focusing on the consequences of exceeding (and returning to) 1.5°C and 2.0°C of global warming. Finally, ongoing research efforts to improve tipping risks assessments and guide future climate policy will be highlighted.

Towards overshoot-proof multi-century sea level projections – an emulator perspective

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Abstract

Potential impacts and risks of overshooting 1.5°C, including triggering irreversible ice loss and a higher multi-century sea-level rise (SLR) commitment, need to be better understood to support well-informed policy and decision making. Exploring overshoot is an emerging scientific priority and will be comprehensively studied in the 7th Assessment Report of the Intergovernmental Panel on Climate Change (AR7). A new set of pathways have been recently developed by ScenarioMIP (the Scenario Model Intercomparison Project) and proposed to inform the framing pathways of AR7. The ScenarioMIP emission pathways include different overshoot scenarios, covering a wide range of peak temperatures and emission reduction rates. Process-based model results forced by these new pathways will provide new calibration data to overshoot-proof existing emulators.

Here, we first present an updated MAGICC-SLR emulator as a first step towards a fully overshoot-proof emulator. The updates include a new calibration for the Greenland ice sheet and different land water storage representations following population assumptions as represented in the Shared Socioeconomic Pathway (SSP) framework. The updated emulator produces results that are consistent with the ranges reported in AR6 for the individual sea level components. We then use this AR6-consistent MAGICC-SLR setup to project multi-century SLR under the ScenarioMIP pathways, thereby exploring the multi-century response of the main sea level components and testing the overshoot behaviour of MAGICC-SLR.

We emphasize the limitations and caveats when projecting SLR under overshoot and on long timescales, in particular with simplified modeling approaches, and outline next steps to continue overshoot-proofing MAGICC-SLR. We highlight the need for a careful evaluation of the parameterizations for each SLR component to ensure a physically robust representation of the (ir)reversible multi-century SLR response under overshoot.

Mapping the current state of knowledge on overshoot: Uncovering trends and patterns in the scientific literature through a bibliometric analysis.

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Abstract

The world is rapidly approaching a mean global temperature increase above the 1.5 degree benchmark set forth in the Paris agreement, and it is increasingly likely that warming above pre-industrial average will soon pass into a period of overshoot. Policy and scientific communities are increasingly focused on understanding the potential impacts of an overshoot scenario and are concerned with better grasping the peak warming and drawdown trajectories that exceeding 1.5 of warming could take. Though peer reviewed literature has advanced quickly over several years, knowledge production has been skewed toward specific disciplines, geographies, and certain types of possible impacts. Importantly, focus has been largely placed on physical systems and climate systems, with less emphasis on understanding the social impacts of overshoot and associated tipping elements. To date, only a small set of reviews systematize the extant knowledge on the impacts of overshoot and more work is needed to understand what may occur and how those impacts could affect policy and eventual drawdown. Our study presents a bibliometric analysis of the current overshoot literature based on studies included in the Web of Science database. Through graphic visualization, we analyze the thematic, topical, network, and geographical patterns in the extant literature and present a systematic overview of the current state of overshoot science. Importantly, our analysis highlights specific centers of knowledge production, scientific interconnectivity, as well as gaps in knowledge production across geographic and thematic dimensions. We summarize what is currently known with regard to social impacts and tipping elements, and highlight key areas, both geographic and topical, where knowledge production efforts could assist in building more robust understanding of the impacts and possible trajectories of overshoot.

Southern Ocean deep convection in a cooling world - a tipping element?

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Abstract

The ocean accumulates carbon and heat under anthropogenic CO₂ emissions and global warming. Little is known about how the ocean will release heat and carbon under net-negative emissions and global cooling, that is in an overshoot scenario. Here we use an Earth system model of intermediate complexity and show results of an idealized climate change scenario that, following global warming forced by an atmospheric CO₂ increase of 1% per year until CO₂ doubling, features subsequent sustained net-negative emissions.

After several hundred years of net-negative emissions and gradual global cooling, sudden discharge of heat from the ocean leads to a global mean surface temperature increase of several tenths of degrees that lasts for more than a century. This ocean heat "burp" originates from heat that has previously accumulated under global warming in the deep Southern Ocean, and emerges to the ocean surface via deep convection. The deep convection is accompanied by a rearrangement of the global overturning circulation. Little CO₂ is released along with the heat which is largely due to particularities of sea water carbon chemistry. As the ocean heat loss causes an atmospheric temperature increase independent of atmospheric CO₂ concentrations or emissions, it presents a mechanism that introduces a breakdown of the quasi-linear relationship of cumulative CO₂ emissions and global surface warming (TCRE).

The enhanced heat loss from the Southern Ocean lasts for about two centuries, and the reorganisation of the global overturning circulation persists thereafter. That is, in our model simulations, Southern Ocean deep convection tips the ocean into a new state for at least half a millenium. We call for assessing the robustness of how models forced with net-negative CO₂ emissions simulate durability of ocean storage of heat and CO₂, and pathways of loss to the atmosphere.

("Southern Ocean heat burp" currently in review at AGU Advances.)

A probabilistic risk assessment of interacting tipping elements under overshoot scenarios

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Abstract

As the 20-year global warming average is now dangerously close to 1.5C, almost certainly leading to an at least temporary overshoot past 1.5C (Bustamante et al. 2023, <https://doi.org/10.1017/sus.2023.25>; Bevacqua et al. 2025 <https://doi.org/10.1038/s41558-025-02246-9>) overshoot pathways are increasingly critical to understand in order to avoid or at least reduce the likelihood of having multiple tipped Earth systems. In this work through a probabilistic model of interacting tipping points, each treated as a Markov chain, we provide a risk assessment of nine interacting and co-evolving tipping elements (six global-core elements, two regional elements and the El Niño-Southern Oscillation) under different global warming overshoot pathways, such as SSP5-3.4-OS and other Tier 2 scenarios in CMIP6 as well as the idealised version of the Tier 1 experiment protocols under TIPMIP-ESM. Through this framework we are able to coherently incorporate belief assessments of pairwise interactions (Kriegler et al. 2009 <https://doi.org/10.1073/pnas.0809117106>; Wunderling et al. 2024 <https://doi.org/10.5194/esd-15-41-2024>).

Our results are manifold: first, we provide the probability of each element being tipped evolving over time; for example we find that even under an optimistic overshoot (SSP1-2.6) the coral reefs are very likely to have tipped by 2100 and remain likely to do so by 2350. Second, given the estimated impact of each tipped element on global warming (Armstrong McKay et al. 2022, <https://doi.org/10.1126/science.abn7950>) we provide the expected impact (i.e. expected increase in global warming due to a tipped element) of overshoots as mediated by interacting tipping elements. Finally we incorporate the feedback from the combined impact of the tipping elements with different background GWL forcing under the different pathways to see whether interactions exacerbate or ameliorate the effects of overshoots.

Non-linear permafrost response to overshoot

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Abstract

The northern permafrost regions contain significant amounts of carbon and are warming at approximately 3-4 times the global rate. Understanding the response of these carbon stocks under policy-relevant overshoot scenarios is a priority for climate policy.

Here, we use output from a simple climate model to drive the UK land surface model JULES, with an improved, more explicit representation of permafrost processes compared to the standard version used in CMIP6. Our simulations include probabilistic estimates of uncertainty in future projections derived from climate sensitivity and the spatial patterns of CMIP6 ESMs.

With the standard version of JULES, permafrost extent is reversible even under high warming levels. The improved version of JULES shows a delayed recovery of permafrost extent beyond 2300 (i.e. no recovery had begun). In addition, the northern high latitudes carbon balance transitions to a source of carbon between 2050 and 2100, and despite the temperature falling again remains a source until 2300 in many of the simulations, i.e. largely an irreversible change.

Global glacier response under overshoot

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Abstract

The global loss of mountain glaciers is contributing to sea-level rise and affecting regional water availability. Quantifying the timing and magnitude of future glacier loss is critical to inform adaptation and mitigation strategies. To date, glacier change under overshoot scenarios, where global temperatures exceed a target before returning to it, has not been quantified. In this study, we present new simulations of global glacier volume and runoff produced within the EU-funded project PROVIDE (<https://www.provide-h2020.eu>). We show that, due to the time-lagged response of large, predominantly high-latitude glaciers, a scenario peaking at 3.0°C before returning to 1.5°C results in 11% more global glacier mass loss by 2500 compared to a scenario stabilising at 1.5°C without overshoot. In basins where glaciers regrow after an overshoot, glacier runoff reduces further than if climate were to stabilise at 1.5°C, a newly documented phenomenon we term “trough water”. Our study highlights regionally heterogeneous overshoot impacts on glaciers, with implications for both sea-level rise and water availability in downstream regions.

Theme 6: Adaptation and adaptation limits under overshoot

Chair: Kristie L. Ebi, Marina Andrijevic

The severity of climate risks under overshoot depends markedly on societal adaptive capacity, as well as the potential transgression of limits to adaptation. The coincidence of overshoot and low adaptive capacity can amplify climate risks. This has profound consequences for the ability to achieve climate-resilient and equitable development outcomes under overshoot, in particular, for the most vulnerable countries, communities and peoples. This session will explore the complexities and challenges of adapting to climate change under overshoot scenarios. We will be taking an explicit pathway perspective on adaptation to explore key questions such as whether prospects of potential long-term impact reversal matter for adaptation needs and decision making. Irreversible impacts under overshoot, especially on sensitive ecosystems, could risk transgressing adaptation limits. To be effective and efficient, adaptation planning needs to incorporate the possibility of an overshoot, and what that could mean for adaptation limits,. The session will also focus on incorporating principles of equity and fairness in adaptation planning that accounts for overshoot.



Episode 7: Adaptation and adaptation limits under overshoot with Kristie L. Ebi

Complimentary qualitative and quantitative methods for climate risk assessment and adaptation: Urban heat in Lisbon and Islamabad

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Abstract

Urban heat hits hard and unequally, stressing people's health, education, and livelihoods. Impacts vary greatly owing to wide ranges of social and physiological vulnerability to urban heat, capacity to cool living and working spaces, and spatial patterns of heat across the urban fabric. Too often these factors combine so that people that face the most intense heat are also least able to cope with its impacts. Here we show an approach to combine on-the-ground local knowledge of heat impacts from qualitative interviews with quantitative socio-economic data and high-resolution urban heat modelling for present and future climates. This provides more holistic insights than could be achieved with any one of these methods in isolation. We investigate impacts of and adaptation to urban heat in Lisbon, Portugal and Islamabad, Pakistan, interviewing key local informants (N=49) in schools, hospitals, construction sites, and other indoor and outdoor work settings. This reveals diverse impacts and small-scale adaptation, further showing that both impacts and adaptive capacity are unequally spread across socio-economic groups. Geospatial analysis of urban heat modelling and social vulnerability indicated by census data reveals spatial patterns where high urban heat intersects with socially vulnerable groups. A current-policies climate scenario results in substantial increases in societal exposure to urban heat, with even large-scale adaptation options only able to slightly decrease its impact. These findings highlight the urgency of climate mitigation as well as the need to focus adaptation strategies on those people most impacted by and least able to cope with urban heat.

Urban informal settlements uniquely adapt to flooding: evidence from a systematic review of risks associated with responses in Africa

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Abstract

Studies on risks associated with flood-induced vulnerability and hazards in urban informal settlement are now available and representative of a wide range of contexts. But what is yet to be deeply articulated are risks stemming from responses to different types of flooding across urban informal settlements. Using a qualitative systematic review of scientific research and project case studies, this paper examines the risks associated with responses to coastal and flash floods, and the simultaneous occurrences of both in African urban informal settlements. The paper draws on evidence from a systematic review which conducted queries on titles and abstracts in the Web of Science and Scopus literature databases in April 2024. Groups of keywords connected with overarching research question -how do urban informal settlements in Africa respond to coastal and flash flooding and the attendant risks- were useful in filtering both peer-reviewed papers and project case studies from non-academic literature.

The responses that stand out in the 200 academic publications and 50 local adaptation projects selected, mainly include continuous refurbishment of housing units; alternative sewer and sanitation facilities; rainwater harvesting; elevating, grassing and de-silting roads and drainages; communal bridges for safe passage and accessing essential services; creation of local evacuation teams in collaboration with external partners; voluntary immobility; temporary and permanent relocation to safe havens. Although these responses demonstrate evolving local adaptation capacities, the risks therefrom are disruptions in improvements of physical infrastructure and green corridors, destroying wetlands, exposure to water and air-borne diseases, tensions and strains accentuated by violence due to confined living conditions. Pathways to traversing these risks would require identifying and addressing the barriers to collaborative flood management, since actions by organized groups in informal settlements hold co-benefits for improving the overall quality of adaptation at wider scales.

Climate Overshoot and Insurance Retreat: Mapping Emerging Uninsurability in India, the Philippines, and Mexico

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Abstract

As the world faces the prospect of exceeding the 1.5°C global warming threshold, the role of insurance as a climate adaptation mechanism is under growing threat, particularly in vulnerable regions of the Global South. Insurance markets are retreating from high-risk areas, leaving households, communities, and subnational governments exposed to escalating financial shocks. This study introduces a novel *Uninsurability Index* to identify and map subnational zones where intensifying climate hazards intersect with weak insurance systems and high social vulnerability, giving rise to persistent “adaptation blind spots.”

The analysis focuses on three climate-exposed countries—India, the Philippines, and Mexico—each with distinct insurance architectures and risk profiles. Using high-resolution CMIP6 climate projections under the SSP5-8.5 overshoot scenario (<https://www.ipcc.ch/report/ar6/wg1/>), the study assesses spatial exposure to multiple physical hazards: floods and droughts (via precipitation), heat stress (via temperature), and coastal risk (via sea-level rise). These data are integrated with subnational indicators of insurance penetration, claims performance, and program presence, drawing from national programs such as PMFBY in India, PCIC in the Philippines, and the discontinued CADENA and FONDEN schemes in Mexico. Vulnerability is proxied using multidimensional poverty indices and access to social protection.

Preliminary findings suggest that under overshoot conditions, large portions of these countries may enter a regime of structural uninsurability, where insurance retreat is not a temporary actuarial market failure but a lasting constraint on adaptation capacity. This retreat is spatially uneven and closely correlated with pre-existing development gaps. In India, for example, emerging flood and drought hotspots with weak insurance penetration align with areas of high poverty and fiscal stress, echoing broader patterns in projected flood exposure (<https://doi.org/10.1016/j.jhydrol.2024.130734>). In Mexico and the Philippines, the weakening of public disaster insurance programs reflects global trends in climate-driven insurance retreat (<https://www.climatecouncil.org.au/resources/uninsurable-nation-climate-vulnerable-places/>) and the widening protection gap (https://www.eiopa.europa.eu/tools-and-data/dashboard-insurance-protection-gap-natural-catastrophes_en).

This research makes three contributions. First, it operationalises the concept of uninsurability at a spatially explicit, policy-relevant level, offering a transferable framework to track where climate-exposed populations are losing financial protection. Second, it highlights the limits of insurance as a market-based adaptation tool under overshoot, where risk thresholds are exceeded and coverage becomes unviable. Third, it contributes to global debates on loss and damage and climate justice by identifying how uninsurability reinforces structural inequities in adaptation access and fiscal resilience.

The findings support growing calls for anticipatory strategies—including public reinsurance, adaptive social protection, and climate-contingent fiscal instruments—to address protection gaps in a warming world. See also IPCC AR6 WGII (<https://www.ipcc.ch/report/ar6/wg2/>),

UNFCCC Loss and Damage (<https://unfccc.int/topics/adaptation-and-resilience/workstreams/loss-and-damage>), and frameworks on global risk pooling (<https://arxiv.org/abs/2206.13895>).

Climate overshoot and Adaptation - The new policy frontier

Oshea Roopnarian, Professor Shalini Singh

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Abstract

The core function of Adaptation is to build climate resilience amongst communities and ecosystems. However, recently Adaptation initiatives have not matched the rate at which climate change occurs leaving vulnerable nations and marginalised groups, in an overshoot scenario and at great risk of climate hazards such as extreme heat, drought, high sea levels and flooding.

This climate variability coupled with financial, technical and compliance constraints compromises the Adaptation initiatives of vulnerable nations because collapsing infrastructure, poverty and debt are daily challenges that must be met as a priority. While some developing nations have Adaptations plans, these plans are inadequately funded and supported to address all the risks they face. The distinction between Exposure data and Vulnerability data when determining equity considerations has been mooted as a cause for this oversight.

This research intends to explore the limitations of Adaptation and Vulnerability aspects of current policy and implementation practice under an overshoot scenario. A systematic literature review will be used to develop a roadmap to outline potential Adaptation decisions under an overshoot scenario concerning different hazards. Open source Socioeconomic Vulnerability metrics will be the main source of data collection. Validity will be achieved by saturation of information and reliability will be monitored by the repeatability and reproducibility of the information.

This research seeks to contribute to the limited body of knowledge by informing policy development and developing resilience under an overshoot scenario.

Simulating the impact under climate overshoot and agronomic adaptation options for Summer Rice through DSSAT model

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Abstract

Anthropogenic climate change is one of the biggest challenges of the current century. Due to this climate change, Indian subcontinent is becoming very much vulnerable to heat waves as it lies in the tropical and subtropical regions. India is already observing record breaking heat, with 2016 and 2020 being among the hottest years in the current century. Thus, warming in the tune of 1.5°C to 3°C has become a matter of serious concern not only to the climatologists and scientists but also to the policy makers and farmers. In view of this background and considering the power of DSSAT (Decision Support System for Agrotechnology Transfer) model to simulate the crop yield under different weather condition, a research work was carried out to evaluate the impact of agronomic adaptation options for Summer Rice in Lower Indo-Gangetic Plains under climate overshoot. Rice is the most important staple food in Asian countries and Lower Indo-Gangetic Plains play a critical role in India's food grain production contributing approximately 15 to 16 million tons of paddy annually.

The CMIP6 models CNRM-CM6-1, MRI-ESM2-0 and NORESM2-MM were observed as the best performing models for the study region. The future projections indicate 6-20% declined rainfall in the majority of the locations with 2 to 5 °C and 1 to 4 °C rises of maximum and minimum temperatures respectively under SSP5-8.5. During end-century, as high as 7-9 °C higher maximum temperature can be noted under extreme emission scenario. Through calibrated and validated crop growth simulation model, it is observed that early anthesis by 4-10 days and early maturity by 5-15 days will be observed under climate change scenario. These reductions of phenophase-duration vary with different climate change projection scenario. The simulation result shows a loss of yield by 6-11% in mid century and as high as 17% during end-century.

Ultimately the suitable adaptation options to combat the yield loss due to climate change using simple agronomic practices were evaluated through simulation process. The first fortnight of January emerged as the most productive under both projection scenarios generating biomass and yield between 7189-7376 kg ha⁻¹ and 3633-3821 kg ha⁻¹ respectively. It outperformed the other two sowing windows by 3-5% in biomass and 4-7% in yield. DMRT results also confirmed the superiority of this sowing period. Along with the sowing window, the best spacing option and age of seedling for transplantation under climate overshoot were worked out. In case of irrigation management, application of irrigation after three days of drying can be recommended instead of continuous ponding, which will not only minimize the methane emission but also can retain the sustainable yield. Thus the study identifies several optimal adaptation strategies for summer rice cultivation that can mitigate the adverse impacts of climate change.

Assessing the establishment of a network of heatwave refugia in Lisbon (Portugal) under overshoot trajectories

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Abstract

Extreme heat stress events have significant negative impacts on population, particularly in urban settings and for the most vulnerable groups, such as children and the elderly. The creation and application of a network of heatwave refugia offers thermal comfort to populations and supports the climate adaptation of communities in the urban context (Pede, 2024). Typically, the establishment of such networks does not consider future climate projections, particularly those under overshoot trajectories, which might decrease the effectiveness of such adaptation strategy in the future. Knowledge on overshoot trajectories and their prospected impacts is particularly important for adaptation planning at the long-term (Theokritoff, et al. 2025).

The Lisbon Metropolitan Area (LMA) is the most populous area in Portugal and is exposed to a wide range of climatic hazards, in particular extreme heat events and heatwaves. There is current interest from local authorities in the LMA to plan and implement a network of heatwave refugia, but knowledge still lacks on how to proceed and which factors to consider when planning such a network. This work intends to assess the benefits of a hypothetical heatwave refugia network in LMA under overshoot trajectories. We used CLIMADA, an open-source software framework that assesses climate-related risks and evaluates adaptation options, considering the existing hazards (i.e. heatwaves in our study), exposures (i.e. population in our study) and vulnerability to the hazard. Three heatwave scenarios based on climate overshoot trajectories from the PROVIDE project (<https://climate-risk-dashboard.iiasa.ac.at/>) were used as hazards. More than 4000 churches, museums, malls and libraries were identified as possible heatwave refugia for the LMA population. A distance buffer was created around each refugia to represent the population that would use the refugia during a heatwave. Different distances were applied per overshoot trajectory, based on the perceived cost-effectiveness during a heatwave event. Results show that the heat refugia network effectively reduces the exposure of population to heat. However, not many buildings meet the conditions to be considered refugia in LMA peri-urban areas, diminishing the climate adaptation capacity of communities in those areas. Further research into the topic should include demographic groups as factors in the modelling, particularly the most vulnerable, and the assessment of a wider range of infrastructures for inclusion in the refugia network, such as green parks and small private commercial spaces, especially in peri-urban and less affluent areas.

Climate overshoot implications for local adaptation planning

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Abstract

As global warming increases, the topic of overshoot, understood as the temporary exceedance of the 1.5°C limit of the Paris Agreement, is gaining prominence both in scientific and political spheres. However, overshoot and its implications for adaptation in the short-term and long-term remain unexplored.

In this Perspective piece, we first reflect on the current use of global climate scenarios and local impact projections in science-based adaptation planning. The risks specifically arising from overshoot scenarios in relation to the transgression of limits to adaptation and impact irreversibility are highlighted. While overshoot may not be relevant for short-term planning, it should be considered for long-term plans and policies, for example for infrastructure-based measures and for irreversible impacts such as sea-level rise.

Then we use a simple mathematical model for economics of climate adaptation to explore how — assuming that the occurrence of an overshoot can be anticipated — the overall costs of adaptation (accounting for the implementation of adaptation measures and avoided damages) would vary depending on whether one chooses to adapt to impact levels at peak warming or after overshoot. The influence of the cost and efficiency of the adaptation measures, the magnitude and duration of the overshoot, as well as economic parameters (growth and discount rate on protected assets) is also investigated. We find that the prospects of potential long-term impact reversibility may have limited relevance in most adaptation decision-making contexts, indicating that it might be peak warming, rather than a long-term outcome, that determines adaptation needs and costs.

Finally, key insights from adaptation practitioners in four diverse urban vulnerability contexts (Bodø, Lisbon, Nassau, Islamabad) are presented on how these risks are perceived and integrated (or not) into local planning and policy-making.

Overall, we argue that current adaptation planning must be extensively evaluated against a wider set of future global climate outcomes to incorporate risks of transgression of local limits to adaptation and overshoot. To this end, data gaps on adaptation limits and impact reversibility need to be filled and capacity building needs on climate scenarios, overshoot and related concepts for local adaptation practitioners should be addressed.

Mainstreaming overshoot considerations into adaptation planning: lessons from four regions around the world

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Abstract

As current global efforts remain insufficient to keep warming levels to no more than 1.5°C, the Earth system is increasingly likely to experience more intense impacts from climate change. Even under a temporary climate overshoot scenario, many impacts will be amplified by Earth-system feedbacks, potentially prolonging and making them irreversible. While the likelihood of at least a temporary overshoot is becoming increasingly unavoidable under current policy and emission trajectories, traditional adaptation planning and efforts do not take into account the time horizons or impact irreversibility of climate overshoot. As a result, adaptation policies may be exposed to unforeseen consequences, resulting in maladaptation, exceedance of hard and soft adaptation limits, and permanent loss of adaptation measure options in some cases.

Although scientific knowledge on overshoot pathways is growing, its implications for long-term adaptation planning remain underexplored, especially in policy and practice. Few national adaptation strategies consider timeframes beyond 3 decades. Yet, even under the most optimistic and nearly-fully reversible overshoot scenarios, [time horizons of 50 years or more may be required to adequately account for peak warming and long-term reversal](#). Existing adaptation efforts are already constricted by soft limits, such as access to finance, local capacity, and institutional knowledge, which disproportionately affect highly vulnerable countries with constrained adaptive capacity. Since overshoot is projected to occur in the first half of this century, [when adaptive capacity will already be comparatively low](#), current adaptation measures may be largely insufficient.

In order to integrate climate overshoot into ex-ante adaptation planning efforts, actors at the science-policy interface must engage in co-development, capacity building, and knowledge transfer with local adaptation practitioners. This presentation will highlight our experience working with 4 diverse regions (Nassau, Bahamas; Lisbon Metropolitan Region, Portugal; Bodo, Norway; Islamabad, Pakistan), as part of the Horizon 2020-funded PROVIDE project. Results indicate that adaptation efforts vary based on local contexts, political conditions, and capacity, with overshoot largely unconsidered. The provision of data-backed overshoot scenarios, concrete adaptation measures, and high-resolution modelling are measures that allow for local actors to better evaluate and assess long-term strategies that embed overshoot into their local contexts. The results of this study provide a useful path toward integrating overshoot research into local, on-the-ground efforts.

Limits to Urban Heat Adaptation Measures & Overshoot Implications

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Abstract

Recent work by [Yiou et al. \(2024\)](#) projects that extreme heat events of 50°C could occur in Paris if global mean temperature (GMT) exceeds 2°C. Several climate overshoot pathways—such as current policy trajectories and 2020 Nationally Determined Contribution-aligned policies — indicate that this threshold could be reached by 2060. In such scenarios, many other global cities would experience such extremes earlier. Urban temperatures surpassed 50°C in multiple cities in 2024 ([Igini, 2024](#)). These events, likely to become more frequent, pose severe health risks, especially for vulnerable populations, such as very young children, the elderly, unhoused, and low income households. While urban heat adaptation plans and measures are increasingly adopted, plans may not address the limits of their interventions under sustained or extreme heat impacts or outline soft limits which may impede their use in other cities with heat risks. This submission provides: (i) an overview of common urban heat adaptation measures, (ii) examples of best heat practices, and (iii) assessment of their soft and hard limitations, especially as relevant to climate overshoot scenarios. Analysis is based on available literature and through illustrative examples where quantitative numbers are not yet available, following overshoot-proofing sectoral analysis by [Theokritoff et al \(2024\)](#). Measures to be considered include examples of urban cooling methods in precise regions, measures to increase human resilience to heat events (i.e., behavioural change), and disaster response measures (i.e., resource availability, outreach to vulnerable populations). The work in progress concludes by identifying further research relevant to the measures discussed and suggesting cases where greater loss and damage may be experienced.

Understanding and addressing climate adaptation limits in the context of climate overshoot. Are there any hard social limits?

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Abstract

Strong evidence of mounting and increasingly complex disaster and climate-related risks worldwide underscores the urgency of recognizing and addressing limits to adaptation—both soft and hard. Analysts have suggested that social limits are essentially mutable and reversible, i.e. there are no hard social limits. We revisit this hypothesis in light of 1.5C and 2 C overshoot by building on a novel assessment framework of adaptation limits and transformation. This framework can be operationalized either through methods that are driven by climate science and risk assessment; or through a socially constructed lense that highlights the contextual and structural drivers of transformation needs in the context of limits. Drawing on expert review and synthesis of risk management as well as adaptation evidence from IPCC's 6th Assessment Report, we report on risks from heatwaves in ecological and social systems in the context of overshoot. Focussing on tropical coral reef systems, we find clear and robust evidence of hard limits projected to be breached in such ecological systems. Science has shown with very high confidence that there will be widespread loss of structural integrity of tropical coral reef systems already by mid-century and warming of larger than 2°C warming with no sign of reversibility identified.

For social systems and focused on human public health, there is less rigorous evidence, yet we also identify soft limits around the world (labour productivity impaired, outdoor labour worktime rescheduling, severe stress on public health systems). There is also some evidence for potential hard limits as projected for small islands in socio-ecological systems. Some small tropical islands have been assessed to be breaching hard adaptation limits in terms of implementing planned island migration already for a low global emission scenario. Migration decisions have and would be further driven by compounding and cascading risk from interacting human health heat stress, sea level rise and high wave events, reduced land productivity, lack of freshwater, and, where there is dependency, loss of coral reef systems sustaining livelihoods. Eventually such decisions are driven by human agency with multiple risks and issues to be considered, which indicates some level of reversibility. Ultimately, we argue that a genuine socio-ecological systems perspective should integrate both views, facilitating the identification of limits and potential transformational pathways that may allow to better study whether there is reversibility and where adaptation limits may be unmutable.

Adaptation pathways under overshoot scenarios

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Abstract

An overshoot of the Paris Agreement global warming goal, even if temporarily exceeding 1.5°C, will likely result in more severe climate impacts, including impacts that may or may not be reversible over time (Pfleiderer et al., 2024). This can have implications for local adaptation needs, for example as limits to adaptation are reached (Theokritoff et al., 2025). At the same time, the concept of overshoot also entails a longer term stabilisation of global warming to below 1.5°C.

Therefore, adaptation planning under consideration of overshoot requires an approach that can deal with uncertainty. One framework suitable for this are adaptation pathways which allow for robust and flexible long-term adaptation planning. An adaptation pathway outlines a set of adaptation measures over time linked to key decision points at which a switch to another adaptation pathway is possible (Haasnoot et al., 2024). This allows for adaptive adjustments in the adaptation plan as the circumstances change or new information becomes available over time, e.g. quantification of adaptation limits.

In this research, we illustrate how overshoot considerations can alter adaptation pathways for sea-level rise and heat. The two hazards have been chosen to resemble on the one hand, how the stabilisation at 1.5°C or below might reduce some of the adaptation needs which arose during the overshoot period in the case of heat, and on the other hand, how the legacy of overshoot can lead to prolonged and irreversible climate impacts, such as with sea-level rise (Schleussner et al., 2024). We illustrate how adaptation pathways point to key decisions for adaptation and guide adaptation decision-making through uncertainty.

Modelling Overshoot, Missing Society: Political and Social Systems as Central Uncertainties in Climate Overshoot Pathways

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Abstract

Overshoot pathways often rely on under-specified assumptions about the social and political conditions that underpin mitigation, adaptation, and long-term climate recovery. As with the broader climate scenario framework, political and institutional development is typically treated as stable or captured through narratives that lack empirical grounding. Yet it is precisely these factors, including governance capacity, legitimacy, collective decision-making, and armed conflict, that will shape how overshoot is experienced and whether recovery is feasible.

This paper argues that a politically informed assessment of overshoot requires tracing the dynamics and path dependency of political and social systems across the full trajectory of overshoot. To better understand the range of conditions consistent with overshoot pathways, we need a more systematic approach to representing institutional change, governance variation, and societal capacity. First, political and social systems evolve through dynamics that may or may not align with the timing and scale of climate action implied in overshoot scenarios. These include regime transitions, changes in state capacity, structural institutional shifts, and shifting patterns of legitimacy. Second, managing the overshoot period itself will require coordination, long-term policy alignment, and governance innovation under conditions of increasing risk and uneven adaptive capacity. These demands are politically contingent and regionally differentiated. Third, we lack empirical or modelled understanding of the political and social conditions that may prevail during the recovery phase. The IPCC WGII AR6 report, for example, draws primarily on evidence about the impacts of surpassing 1.5°C, but offers little insight into how political and social systems might function during a subsequent decline in temperature.

This gap limits our ability to evaluate the plausibility of overshoot scenarios or to identify pathways aligned with the social and institutional conditions required for successful recovery. To address this, the paper proposes integrating political and social development trajectories directly into overshoot scenario frameworks. This includes using indicators of institutional change, projections of governance quality, and modelling feedback between climate impacts and political dynamics. It also calls for closer integration of insights from social science including political science and historical analogies, to better capture how social and political systems might evolve over the overshoot pathway and to explicitly account for the uncertainty surrounding societal change.

Theme 7: Loss and Damage

Chair: Sindra Sharma-Khushal, Elisa Calliari

Overshoot impacts will cause lasting loss and damage to societies and ecosystems that will fall disproportionately on the most vulnerable countries, communities and people. The session welcomes contributions to advance our understanding of the consequences of overshoot for exceeding limits to adaptation, and resulting in economic and non-economic loss and damages – including among others health, education, cultural heritage, biodiversity, and ecosystem services. We particularly welcome contributions focusing on disaggregation of the harm felt by marginalized groups and how this intersects with their ability to realise their human rights. We also call for a focus on responses to loss and damage at various scales, including the policy contexts and institutional arrangements, and discussing the role of transformational adaptation. Contributions assessing the loss and damage implications of overshoot legacy, as well as potential side effects of large scale carbon dioxide removal are also welcomed.



Episode 8: Loss and Damage with Sindra Sharma

Research Topic: The Future of Pastoralism in the Changing Climate and Modern Land Use Management in Kajiado County, Kenya.

Sammy Oleku^{1,2}, Prof. Christopher Oludhe³

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Abstract

Research Topic: The Future of Pastoralism in the Changing Climate and Modern Land Use Management in Kajiado County, Kenya.

This study aims to examine the future of pastoralism in the changing climate and modern land use management in Kajiado County, Kenya, and develop sustainable, data-driven land use management strategies to address loss and damage, thereby enhancing community resilience. The research is guided by the following questions: How is climate change affecting pastoral livelihoods, particularly in terms of livestock, grazing lands, and infrastructure? Are current land use practices adequate for mitigating these impacts? What innovative strategies can improve resilience and reduce damage? And what are the knowledge gaps among pastoralists and local authorities regarding climate resilience? To achieve these objectives, a comprehensive mixed-methods approach will be employed. First, a literature review will be conducted to synthesize existing knowledge on climate change impacts, land use practices, and resilience strategies in pastoral settings, establishing a theoretical framework and identifying gaps. This review will include academic articles, policy documents, and previous case studies from Kenya and similar arid regions. Secondly, field surveys and structured questionnaires will be administered to a representative sample of pastoralist households. Quantitative data on livestock losses, grazing land conditions, water access, and adaptation methods will be collected to quantify the extent of climate-induced loss and damage. The questionnaires will also capture perceptions of climate variability and existing management practices. Thirdly, key informant interviews (KIIs) will be conducted with local government officials, land use planners, climate experts, and community leaders. These interviews will provide qualitative insights into current land management policies, their effectiveness, and the challenges faced in implementing climate adaptation strategies. Focus group discussions (FGDs) with pastoral community members will further explore traditional knowledge, community-based resilience practices, and perceptions about climate risks and solutions. Additionally, geospatial analysis utilizing satellite imagery and GIS tools will be employed to examine land cover changes, grazing land availability, and water resource dynamics over time. This spatial data will help visualize environmental changes, identify hotspots of land degradation, and assess the physical impacts of climate variability on pastoral lands. Data analysis will combine quantitative and qualitative techniques. Statistical software will be used to analyze survey data, identifying patterns, relationships, and the magnitude of climate impacts on livelihoods. Thematic analysis will be applied to interview and FGD transcripts to interpret community perceptions, traditional adaptation strategies, and capacity gaps. Finally, a policy analysis will review existing land use frameworks and climate adaptation policies to evaluate their relevance, implementation, and gaps. This will inform recommendations for strengthening policy measures and integrating community-based practices into formal land management strategies. This research will generate a holistic understanding of climate change impacts on pastoralism in Kajiado, assess current mitigation efforts, identify innovative land management strategies, and address capacity gaps, ultimately fostering resilient and sustainable pastoral livelihoods.

(NB: I am presenting this research paper on 16-18 July 2025 at The University of Leeds, UK at The Scenarios Forum 2025).

The human and social impacts of climate overshoot

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Abstract

The scientific community has produced increasingly robust knowledge and evidence of the physical impacts of warming on time scales of tens of decades and longer. However, the social and humanitarian impacts of climate overshoot remain largely unknown. As we quickly approach mean warming exceeding the Paris Agreement's aspirational goal of 1.5 degrees celsius of global mean temperature rise, new and dynamic climate and social realities of climate overshoot must be considered and managed. Here we outline five factors influencing human and social climate overshoot impacts and call for enhancing action to fill pressing knowledge, data, and policy gaps to understand the risk of irreversible impacts to human and social systems. This information is critical to inform the next round of updating of the Nationally Determined Contributions (NDCs) in 2025 and must be integrated within climate policy, financial mechanisms and governance such as those related to loss and damage.

Financial Instruments as Signals and Mediators of Habitability in the Context of Temperature Overshoot

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Abstract

This paper explores how the weakening or withdrawal of foundational financial instruments—specifically long-term mortgages, property insurance, and municipal bonds—can signal and shape local and regional habitability in a context where particular locations are increasingly exposed to temperature-driven biophysical extremes and stress. It integrates the concept of *temperature overshoot* with the role of financial instruments that historically function to absorb volatility, distribute risk, and support long-term economic and social vitality.

The paper's central argument is that these financial modalities act as under-recognized buffers against systemic climate impacts by enabling liquidity, investment, and risk-sharing. Their deterioration—whether due to repricing, retreat, or reallocation—may precede or amplify local fragility and act as early indicators of declining habitability.

We hypothesize that in regions with exposure to escalating climate risks, observable shifts in financial behavior—such as insurance withdrawal, mortgage tightening, or municipal bond market downgrades—may correlate with declining economic viability and adaptive capacity. The paper uses a desk-based, comparative method drawing on secondary market data, institutional reports, and subnational indicators to examine this hypothesis across six case studies (including California, Florida, Germany, Australia, Pacific Island states, and the UK). These are mapped to the three instruments of interest to examine contrasting dynamics across contexts.

Preliminary findings suggest that the weakening of financial tools can reinforce vulnerability, restrict adaptive investment, and alter population and capital flows—sometimes in advance of measurable biophysical tipping points. This reveals a set of economic early-warning signals for habitability decline that have received little attention in climate impact literature.

The paper contributes a systems-based lens for understanding overshoot not just as a physical or emissions trajectory but as a set of financial and institutional responses with social, spatial, and temporal implications. It offers insights for policymakers, IPCC authors, and climate researchers on the need to integrate financial system behavior into risk and adaptation modeling—particularly where social feedbacks and economic withdrawal may accelerate instability. This framework may support anticipatory policy in regions nearing thresholds of systemic stress.

Resisting overshoot: Justice and repair in ecological loss and damage

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Abstract

Ecological loss and damage (eL&D) in an overshoot world manifests not only as measurable harm to ecosystems and biodiversity, but also as profound non-economic losses, grief, cultural dislocation, and psychological distress, that are experienced individually yet deeply rooted in collective ecological and social ruptures. The submergence of ancestral lands, loss of forests, and biodiversity collapse disrupt shared meaning, place-based identity, and intergenerational continuity, eroding the social-ecological fabric and imposing human and political costs beyond narrow economic valuations. While non-economic losses are central to understanding eL&D, current framings that treat eL&D primarily through this lens risk marginalizing the foundational ecological dimensions that underpin community resilience and wellbeing. Recognizing the inseparability and mutual reinforcement of ecological and non-economic losses is essential for equitable and effective adaptation. In the escalating ecological crisis of an overshoot world, where tipping points threaten irreversible damage, it becomes clear that wellbeing cannot be understood solely as an individual or economic issue. Wellbeing is fundamentally shaped by social structures and the health of ecological systems. Consequently, losses are collective burdens that cannot be borne by individuals alone, nor resolved through narrow governance mechanisms. Addressing ecological loss and damage therefore demands justice-centered, reparative governance that recognizes the inseparability of ecological and social dimensions. Such governance must value ecosystems and biodiversity, integrate ecological realities with human costs, and prioritize proactive habitat protection as both mitigation and reparative action. Crucially, just climate responses must center action, ecological patterns, and place-based identities to ensure adaptation reflects lived realities and upholds justice and irreversible ecological loss.

Keywords: ecological loss and damage, non-economic loss, climate overshoot, irreversibility, tipping points, reparative governance

Overshoot implications for human development and Loss and Damage financing

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Abstract

Climate change has significant impacts on human development, including economic growth and its distribution. Previous work has quantified the current financing needs of a Loss and Damage fund depending on the economic damages and the principles of responsibility. Yet, it is not clear how these social and economic costs will evolve in the future, depending on socio-economic vulnerability, adaptive capacity, and emission scenarios. Here we quantify the impacts of overshoot on dimensions of human development and economic well-being. We use recently developed, encompassing damage functions and climate emulators on multiple dimensions of well-being to understand the duration and depth of overshoot needed to detect significant societal effects. Next, we apply this framework to different, policy-relevant scenarios of varying degrees of overshoot to quantify the Loss and damage consequences of overshoot, under different assumptions of adaptive capacity and economic development. Finally, we perform an extensive sensitivity analysis to quantify the key sources of uncertainty on these estimates, decomposing them between climate feedbacks, socio-economic response, and scenarios. The framework systematically illustrates the extent to which overshoot has negative impacts on society, and the consequences for compensation and liabilities across different countries. We also provide new methods for identifying robust results to the various sources of uncertainty in the climate-economy feedbacks.

Theme 8: Legal and justice implications of overshoot

Chair: Lavanya Rajamani, Gaurav Ganti

Climate overshoot highlights the limits of international legal frameworks in addressing climate harms and delivering justice. International legal frameworks emphasize state obligations to prevent overshoot and mitigate its impacts, yet gaps in ambition, accountability and equity persist. Overshoot disproportionately burdens vulnerable communities, and future generations, who will face irreversible loss and damage, escalating costs of addressing runaway temperature rise, and be reliant on unproven technologies like carbon dioxide removal. This session welcomes contributions that explore the legal and justice implications of target breach and consequences for establishing accountability for climate overshoot. These may reflect on the cross-generational rights implications of overshoot, responsibilities for enabling (and paying) for carbon dioxide removal, as well as reparative justice frameworks to address irreversible loss and damage. Contributions that focus on opportunities to address these issues, whether through negotiation or litigation, are particularly welcome.

Governance of «Overshoot» International Law for returning to 1.5°C (through global net-negative emissions)

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Abstract

Global mean temperature increases are set to exceed 1.5°C compared to pre-industrial levels. In this situation, the most likely scenario to meet the Paris Agreement's 1.5°C temperature goal, foresees *returning* to 1.5°C after temperature excess. This “peak and decline” scenario is referred to by the IPCC as “overshoot”.

In the overshoot scenario, global net-zero emissions will not be sufficient for returning to 1.5°C; they must be followed by global net-negative emissions. In addition to rapid and deep CO₂ and non-CO₂ emission reductions, this requires removing CO₂ (and non-CO₂ gases) from the atmosphere on a global scale. For post-peak return to 1.5°C and reversing temperature excess, global carbon dioxide removals (CDR) must be greater than the sum of global residual emissions so that the total is negative. The extent of net-negative emissions will depend on the duration of exceeding 1.5°C and the magnitude of temperature increase.

This scenario puts the world on an unprecedented track in any respect: scale, scope and urgency. It requires much more ambitious, more rapid, and much better coordinated climate measures than those that were considered necessary for stabilizing temperatures at 1.5°C – measures which already proved to be too demanding. It also requires addressing fundamental questions of global fairness and justice.

This has, so far, been little discussed in international legal literature. There is no public, political or legal debate on such overshoot trajectory. This paper explores the governance needs (and gaps) for “overshoot”: a world that exceeds 1.5°C, peaks and aim to return to 1.5°C. The scientific legal implications of such overshoot scenario will be discussed, including the relevance of the Paris Agreement, timelines and pathways for global emission reductions and removals, NDCs and climate litigation, as well as the implication for other international law such as UNCLOS, Human Rights treaties, and customary international law.

Overshoot also raises pertinent questions about equity, global justice and just transitions, which this paper will map.

Keywords: Overshoot, exceeding 1.5°C, return, Carbon Dioxide Removals (CDR), net-negative emissions, Paris Agreement, equity and justice

Evaluating progress towards climate targets with consistent national remaining carbon budgets

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Abstract

The proportionality between cumulative anthropogenic CO₂ emissions and the increase in global mean surface temperature translates into a global remaining carbon budget (RCB) for each temperature limit. Disaggregating the global RCB into national RCBs offers a benchmark to evaluate country-level mitigation obligations and identify instances of national overshoot. National overshoot refers to the extent to which a country's cumulative CO₂ emissions exceed its fair share of the global RCB, and thus the required amount of net negative CO₂ emissions to balance out the exceeded national RCB. National RCBs have gained relevance in the legal context, most notably in the prominent 2024 ruling of the European Court of Human Rights (ECHR) in *KlimaSeniorinnen vs. Switzerland*, where Switzerland's RCB was central to the court's argumentation.

However, consistent estimates of national RCBs are complicated by mismatches in the accounting methodology of anthropogenic CO₂ between scientific studies and how countries report their emissions in national greenhouse gas inventories (NGHGI). These methodological discrepancies have so far largely been overlooked in legal and political contexts. Here, we quantify how the alignment with NGHGI accounting reduces the global RCB. We calculate NGHGI-consistent national RCBs from 1990 onwards for a wide range of allocation methods and countries, highlighting that national RCBs inherently depend on normative choices.

Interpreting Paris Agreement equity principles, we find large global inequalities and a lack of progress towards achieving the agreed targets. We estimate that by 2025, 64–85 UNFCCC member states (representing ~50% of global GDP) have exceeded their fair-share RCBs for staying below 1.5 °C with 50% likelihood. Furthermore, 41–61 UNFCCC member states (~40% of global GDP) have already overshoot their 2 °C (66%)-compatible RCB.

We identify a methodological inconsistency in the ECHR's ruling and provide revised, NGHGI-consistent RCBs suitable for future legal applications. Even if national RCBs are unlikely to directly drive global climate negotiations, they serve as a scientifically robust basis for assessing national overshoot, attributing responsibility, and potentially informing reparative justice mechanisms. Our approach enables transparent national RCB calculations that are consistent with CO₂ accounting in national policy frameworks, and thus strengthens the scientific basis for future climate litigation.

Legal constraints on solar radiation modification as a response to temperature overshoot

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Abstract

A growing body of literature argues that states are required to minimise the magnitude and duration of overshoot of the Paris Agreement's temperature goal ([Stuart-Smith et al, 2023](#); [Rogelj and Rajamani, 2025](#)). The thrust of this argument is that urgent emission reductions are necessary. However, it could also be understood as providing implicit support for solar radiation modification (SRM): efforts to limit global warming by reducing the amount of solar radiation reaching the Earth's surface, for example by injecting reflective aerosols into the stratosphere. This paper analyses the application of international environmental law to SRM. I argue that while there is a degree of ambivalence within the climate change regime itself, the deployment of SRM as a response to temperature overshoot is constrained by the wider legal framework.

I begin by rejecting the claim that SRM is 'directly applicable' to the achievement of the 1.5°C temperature goal ([Horton et al, 2016](#)). Read in light of the United Nations Framework Convention on Climate Change (UNFCCC), this goal is to be achieved through the stabilisation of greenhouse gas concentrations in the atmosphere – an effort which SRM cannot advance, and may undermine by deterring mitigation. However, I suggest that a more limited claim should be taken seriously: SRM could indirectly support the fulfilment of the UNFCCC's objective by temporarily ameliorating some of the dangerous effects of climate change, analogously to adaptation ([Stoll and Krüger, 2022](#)). Viewed in isolation, this objective could support the evolution of the regime to enable SRM given the ongoing insufficiency of mitigation efforts.

Crucially, I argue that the climate change regime *cannot* be viewed in isolation. Rather, it must be placed within the wider context of international environmental law. The risks posed by SRM engage states' obligations under the Convention on Biological Diversity and the Vienna Convention for the Protection of the Ozone Layer. I argue that recent developments within both regimes have significantly strengthened their applicability to SRM. The long-standing prohibition on geoengineering established by the Conference of the Parties to the Convention on Biological Diversity was not only reaffirmed in 2024, but also seemingly given stronger legal status. Moreover, the legal reasoning underlying the extension of the ozone regime to address non-ozone-depleting hydrofluorocarbons implies that it has a mandate to address both a wider range of proposed methods of SRM and of related risks.

Finally, I suggest that the implications of international environmental law principles for SRM require greater attention. Recent literature has explored how these principles may constrain SRM where they are independently binding under customary international law ([Sulyok, 2025](#)). I argue that principles such as harm prevention, precaution, and intergenerational equity must also inform the interpretation of states' treaty-based obligations on SRM, given their incorporation into the relevant regimes. These principles provide a shared normative framework capable of mediating between the divergent objectives of each regime. This framework could influence future negotiations on SRM, helping to ensure that responses to temperature overshoot do not create new risks for vulnerable communities and future generations.

Schrödinger's Target in the European Climate Law: Missed, Met, or Both?

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Abstract

Global warming is on track to overshoot 1.5 °C above pre-industrial levels. But how does this physical reality sit with the legal framework of the European Union? The European Climate Law (ECL) enshrines a binding objective of climate neutrality by 2050, followed by net-negative emissions thereafter (Art. 2(1) ECL). This long-term goal is supported by interim targets for 2030 and 2040 (Art. 4(1), 4(3) ECL), forming the EU's core climate target infrastructure.

Despite its structured appearance, the law embeds substantial legal flexibility. First, the meaning of "net zero" rests on vague definitions of carbon dioxide removal (CDR), which is tasked with multiple, sometimes competing, functions in EU law. Second, the law imposes no binding limits on the contribution of CDR to the 2050 neutrality objective and net-negativity aim: after 2030, the sequencing of reductions and removals is not specified. This legal design permits overshoot to be accommodated implicitly: missed interim targets can be rationalised *ex post* if enough removals are achieved later.

The argument of the presentation proceeds in three steps. First, it assesses the legal specificity of the neutrality objective, net-negativity aim, and interim targets in terms of their reliance on CDR. Second, it examines the institutional distribution of interpretive discretion - highlighting the European Commission's central role in shaping compliance trajectories. Third, it reflects on the broader normative implications of 'performative law': a regime where climate targets may be legally met, even if practically missed.

To answer the initial question: the European Climate Law does not merely tolerate overshoot - the presentation argues that it structurally enables it. Without clearer definitions, enforceable constraints on removals, and strict accounting separation between mitigation and removals, the EU's climate targets risk becoming Schrödinger's target - both met legally and missed practically effectively limiting enforcement and accountability avenues.

Integrating attribution science to inform legal accountability for overshoot

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Abstract

Climate temperature targets play a key role in litigation seeking accountability for climate change. However, the goal of limiting warming to 1.5C is a political target, not one solely defined by science. As rising emissions and temperatures portend the inevitability of overshoot, examining both the scientific and legal landscapes supporting climate targets becomes key to charting a justice-oriented path forward. Temperature-based targets, for instance, obscure the importance of human rights, tipping points, and short lived climate pollutants, while a concentration-based target does not adequately address the impacts that occur in the interim, some of which may be irreversible. To bridge this gap, source attribution research, which identifies and quantifies the contribution of specific emission sources to climate impacts, provides a pathway to accountability by tracing emissions that lead to overshoot to their origin. Regardless of the target metric, this type of research identifies the origin and magnitude of emissions and potential future reductions, establishing a scientific framework that incorporates both rising emissions and the potential for negative future emissions using emerging technologies like carbon capture and storage and carbon dioxide removal. Overshoot followed by carbon removal to reduce atmospheric greenhouse gas concentrations has clear implications for justice, particularly since the technologies required are not available at scale, tend to be more expensive than renewable energy, and perpetuate existing social inequities. Source attribution methodologies also allow scientists to understand the impacts of past emissions on intergenerational justice. Here, we explore the scientific evidence and methodologies that can be used to redefine climate targets in both a legal and scientifically useful way, while exploring the justice implications of current proposed approaches. We close by describing the research required to trace accountability for overshoot, and the ways in which obligations for mitigation can be reworked to better represent the inevitability of overshoot.

Justice Implications of Climate Overshoot: Mapping Responsibilities Across Mitigation, Adaptation, and Loss & Damage

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Abstract

This contribution conceptualizes a research agenda examining justice implications of a rapid scaling of carbon dioxide removal (CDR) technologies, which are an increasingly essential component of pathways that temporarily exceed the 1.5C warming target established by the Paris Agreement. We focus on how different CDR technologies and the extent of their deployment interact with societal provisioning systems and create new patterns of distributing burdens and benefits across regions and generations. These choices have potentially far-reaching consequences for development, adaptation and Loss and Damage. We argue for more systematic engagement with these trade-offs in scenario design and interpretation and aim to spark dialogue on how justice-centered approaches can guide more equitable climate policy design. The research agenda we outline responds to the critical gap between techno-economic assessments of CDR potential and systematic analysis of how these interventions interact with existing inequalities and create new forms of burden-shifting across spatial, temporal, and social dimensions. Ultimately, we seek to inform the development of safeguards, equitable benefit-sharing mechanisms and governance frameworks that can prevent CDR deployment from reproducing existing inequalities or creating new ones.

Growing up under overshoot: implications for climate litigation

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Abstract

Overshoot creates particular challenges for current young generations, who are expected to live a substantial part of their lives under the overshoot period if it were to occur. Here we first identify the implications for lifetime extreme event exposure under two 1.5°C-compatible warming scenarios whereby CO₂-concentration and mean temperature overshoot by 50 ppmv and 0.35 °C, respectively, by mid-century. Second, we quantify the impacts of near-term emissions from individual projects through a range of indicators and explore the implications for ongoing climate litigation in Europe, with a particular focus on permitting cases.