RESEARCH & INNOVATION

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PERIODIC SCIENTIFIC REPORT

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Principal Investigator names:	Benjamin Sovacool, Jan Christoph Minx, Keywan Riahi
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Project[1] acronym:	GENIE
Project title:	GENIE: GeoEngineering and NegatIve Emissions pathways in Europe
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The report is elaborated on the basis of the:	Grant Agreement with reference AMD-951542-4

[1] The term 'project' used in this template equates to an 'action' in certain other Horizon 2020 documentation

[2] The home page of the website should contain the European flag which is available in electronic format at the Europa website (European flag: http://europa.eu/abc/symbols/emblem/index_en.htm) and the Horizon 2020 programme name.

Project[1] Number: 951542

Project Acronym: GENIE

Project Title: GENIE: GeoEngineering and NegatIve Emissions pathways in Europe

Synergy MID-TERM Periodic Scientific Report
Part B

Period covered by the report: from [01/05/2021] to [30/04/2023]

[1] The term 'project' used in this template equates to an 'action' in certain other Horizon 2020 documentation

Summary of the major achievements since the start of the action

1 - Explain in a clear manner the work performed during the period covered by this report (the entire lifetime of your research project for the final report) along the main objectives/activities foreseen in the Description of the Action.

Please connect each achievement, where appropriate, with the relevant publication/conference presentation indicated in the other sections.

Please specify the outcome in terms of:

1.1 Research and technological achievements along the main objectives/activities (in line with the Description of the Action)

The GENIE team advanced multiple aspects of its research agenda while taking key steps to integrate and synergize activities between the project partners. To date we have held 4 multi-day in- person meetings at each of the partner institutes, alongside regular bi-monthly online meetings. Each institution has hosted partner stays. Collaborations are deepening with the publication of joint journal articles using primary data gathered in the first phase of the project, through the State of CDR report, and GENIE Knowledge Hub.

GENIE researchers played a major role in establishing a new flagship science assessment on carbon dioxide removal (CDR) together with researchers of other major CDR funding lines in Europe called “The State of Carbon Dioxide Removal”. The report fills fundamental knowledge, data, and implementation gaps by assessing technology, policy, scenario, and other aspects of CDR, while making the underlying data freely available. G. Nemet and J. Minx were two of the four co-conveners of the 1st edition, while 11 GENIE researchers contributed to the report. The report has served as a major integrative element within the project. For version 2 of the State of CDR report that will be published in 2024, four out of six conveners come from the GENIE consortium: M. Gidden, W. Lamb, G. Nemet, and J. Minx. All of the five chapters led by GENIE researchers are underpinned by at least one important scientific contribution in a peer-reviewed scientific manuscripts at different stages of publication.

The AU team reports multiple achievements in this scientific reporting period. The team conducted 125 interviews with experts covering the technical, economic, political, and social dimensions of CDR and SRM. The interviews were complemented by an expert elicitation survey. The extensive data collection resulted in 12+ peer-reviewed publications in high-ranking journals. These examine the core opportunities, challenges, barriers, and drivers of a range of CDR and solar geoengineering technologies, along with preliminary identification of most promising technologies. Aarhus planned, pilot-tested, and implemented a large-scale public-perceptions exercise consisting of surveys and focus groups in 30 countries. The survey had a high representation of publics in the Global South at a level that is broader and deeper than the entirety of the existing literature on climate-intervention technologies.

MCC has managed to build up a comprehensive machine-learning infrastructure required to deliver GENIE outputs and applied this infrastructure for its scientific outputs. This enables analysis that was previously infeasible. For example, as public perceptions for emerging CDR and SRM technologies assessed in surveys might be biased due to a lack of awareness of these technologies in the general public, MCC developed an approach rooted in AI to triangulate this evidence by assessing public sentiments and emotions for these technologies by people who engage with the topic on social media without being asked. Similarly, MCC contributed to quantifying global CDR deployment for this first time as well as quantifying and mapping the scientific literature on CDR highlighting that it could be almost ten times larger than previously estimated. Foundational MCC research further identifies a substantial gap in CDR with regards to countries’ short- and long-term ambitions for scaling CDR that threatens reaching net-zero emissions. Finally, MCC has finished deriving the first estimates of CDR potential in cities that opens up a new, neglected policy discourse and informs it with scientific evidence.

The IIASA team reports progress on scientific publications; model development; data analysis; and development of the GENIE Hub where much of the project outputs will be made publicly available. In the publication “Policy guidance and pitfalls aligning IPCC scenarios to national land emissions inventories” for the first time, gross negative and positive land-use emissions pathways have been developed. This analysis fills a key gap required to establish and update mitigation benchmarks for use by the UNFCCC Global Stocktake. The work of the IIASA team has focused on key modelling improvements in the areas of technology granularity; better representation of governance needs for CDR; and climate projections. The creation of a new integrated assessment model was completed, linking two well-established sectoral models, the land-use model MAgPIE and the energy system model MESSAGEix. The team conducted the first integrated assessment of combined CCU and CCS processes via plastics production from biogenic feedstocks in the context of climate mitigation pathways of the petrochemical industry.

The team at UW Madison reports progress on aspects of learning, diffusion, and the adoption of CDR technologies. Efforts have been focused on two main domains. First is a largely quantitative effort to measure rates of upscaling in historical technologies across different national contexts. Second is a deeper, slower, qualitative approach which uses a structured process of historical analogue research to look in detail at the factors affecting the upscaling rate of comparable historical technologies, as well as the risks and challenges that these technologies faced. Both will allow to draw parallels to CDR and SRM technologies and how they might develop in the future. In both of these efforts, progress has been dominated largely by the establishment of infrastructure, collection of data, and development of methods to answer these questions. For instance, we have established a dataset of 166 technologies across many countries, resulting in hundreds of separate historical time series categorized according to complexity, customization, sector, and other characteristics. We have also developed functions to calculate the growth rates of these technologies.

1.2 If applicable: novel methodologies, and/or inter-disciplinary developments, and/or knowledge and technology transfer.

MCC reports progress on scalable machine-learning methods to map the scientific literature and assess attributable climate impacts. Understanding climate impacts is critical in the context of solar geoengineering. Recent climate change assessments such as those by the Intergovernmental Panel on Climate Change have historically struggled to build comprehensive evidence on observed and attributed climate impacts. GENIE research led by MCC has developed a methodology for compiling comprehensive evidence based on observed climate impacts attributable to anthropogenic climate change. The language model BERT was used to identify and classify studies on observed climate impacts, producing a comprehensive machine-learning-assisted evidence map. By combining this spatially resolved database with grid- cell-level human-attributable changes in temperature and precipitation, we infer that attributable anthropogenic impacts may be occurring across 80% of the world's land area, where 85% of the population reside. We believe that this provides a prototype for a new suite of scalable methods that can directly inform climate change assessments such as those by the IPCC with vast lines of synthetic evidence.
Living evidence bases for CDR research: there is a frequent disconnect in evidence-based policy that robust scientific information on a specific policy issue is usually not available during the narrow time window when it would be most urgently needed in policy. This has been a long-standing challenge but crystallized most visibly during the Corona pandemic. MCC has contributed to the development of a living evidence model that is aimed to overcome this bottleneck for evidence-based policy by updating high-quality reviews with high frequencies.
In the publication "Policy guidance and pitfalls aligning IPCC scenarios to national land emissions inventories" the IIASA team has developed an approach to combine the Grassi 'Rosetta Stone' for translating between UNFCCC LULUCF inventories and modelled pathways together with an application of the reduced-complexity OSCAR model which when combined can provide an estimate of indirect and direct fluxes of gross emissions and removals.
The results of the study "Fairness and feasibility in deep mitigation pathways with novel carbon dioxide removal considering institutional capacity to mitigate" emphasize the importance of further investment and development of novel CDR technologies for post-net-zero CO2 mitigation.
The IIASA team has developed a range of approaches to take technology cost learning and granularity into account in an energy system model (MESSAGE). The work was built upon existing IIASA work on separating technology cost learning and economies-of-scale effects in novel technology cost reduction. Using these approaches, the tradeoff between technology learning and scaling up the size of a technology can be quantified using the model. The IIASA team has also supported consortium partners in adopting the IAMC data format and common data conventions for easier sharing of research data.
UWISC reports the Systematic Historical Analogue Research for Decision-making methodology is a novel methodology that we have developed and published using a pilot study. SHARD addresses a persistent problem in the use of historical evidence for studies of low-carbon transitions and other processes of large-scale technological change. This means that people using historical analogues to provide insights about low-carbon transitions are often open to accusations of cherry picking. The SHARD methodology addresses this by systematically establishing a list of metrics by which a historical analogue is compared with a present or future target innovation, then using these to narrow down a long list of candidate historical analogues until one is chosen for more in-depth research.
Our second accomplishment in this area is our database of technological upscaling rates: the Historical Adoption of TeCHnologies dataset.

1.3 Indicate what you would consider to be the (up to) five most significant achievements in your project (e.g. the five most important scientific publications and other research outputs, patents, interactions with stakeholders such as industry or policy makers, media reports or events, etc.).

We consider the following five high-impact journal publications, reports and databases as representative of our most important achievements to date:
-Policy guidance and pitfalls aligning IPCC scenarios to national land emissions inventories, Nature (in review). Provides a novel re-analysis of the IPCC AR6 scenario database to identify the removal component of the land use flux in scenarios, flexibly aligned to both the “bookkeeping” and “national land emissions inventory” definitions. Finds that aligning IPCC scenarios to the latter definition shifts global mitigation benchmarks, with significant implications for the global stock take under the UNFCCC.
-Reviewing the sociotechnical dynamics of carbon removal, Joule.
-Systematic Historical Analogue Research for Decision-making (SHARD): Introducing a new methodology for using historical case studies to inform low-carbon transitions, Energy Research and Social Science. Outlines our SHARD methodology and illustrates it using a pilot study in which margarine is used as an historical analogue for synthetic beef
-The State of Carbon Dioxide Removal, Report. Summarises the state of scientific knowledge on CDR from the perspective of the research landscape, innovation, public perceptions, policymaking, deployment, scenarios and the “CDR gap”. Brings together multiple institutions, projects and experts to provide a balanced and rigorous assessment supported by peer reviewed publications.
-Historical Adoption of TeCHnologies (HATCH) dataset. The product of substantial work hunting down and cleaning various historical data sets on technology upscaling, across multiple countries. This dataset can be analyzed in many different ways to yield useful findings. Once the dataset is made public, it will also be invaluable for other researchers.
-Provision of comprehensive evidence on public perception of CDR and SRM technologies: GENIE provides the first global assessment of public perceptions in an unprecedented survey exercise. Due to potential biases in survey-based methods, this is further triangulated with evidence from social media and media data. This evidence base is currently established in a whole string of publications.
In addition to these research outputs, we report a series of stakeholder engagements, policy engagement and media reporting:
-Testimony to the British Parliament (Benjamin Sovacool)
-Media interview in the Washington Post related to space-based geoengineering (Chad M. Baum)
-Stakeholder interaction with the International Resource Governance Council (IRGC) on “Ensuring the environmental sustainability of emerging technologies for carbon dioxide removal” (Chad M. Baum)
-Online webinar for the State of Carbon Dioxide Removal report, bringing together more than 550 stakeholders from science, businesses, NGOs, governments and international organisations (Jan C. Minx, Greg Nemet).
-Three international media briefings on the State of Carbon Dioxide Removal report for Asia and Oceania, Europe and UK/ North America, attended by about 100 journalists from all over the world. Subsequently the report achieved global coverage with more than 550 media articles (Jan C. Minx, Greg Nemet).
-Impact on policy, with the State of Carbon Dioxide Removal report cited multiple times in a document on the treatment of removal activities under the Article 6.4 mechanism of the United Nation’s Framework Convention on Climate Change. At the European level the report provides a central reference in various places in the draft report for a regulation of the European Parliament and of the Council establishing a Union certification framework for carbon removals (Jan C. Minx, Greg Nemet).

1.4 Would you consider any of these significant achievements as breakthroughs or as advancing a research field significantly beyond the state of the art? Were any of these unplanned/ unexpected? Give a brief explanation.

One significant breakthrough corresponds to the broad expertise provided in relation to analysis of the sociotechnical, political, economic, and environmental implications of climate-intervention technologies undertaken through large-scale expert interviews, surveys, and focus groups. In rather short time, GENIE has been positioned as a leading voice and source of expert analysis on climate-intervention technologies. Another significant breakthrough are the emerging insights related to public perceptions in the Global South of climate-intervention technologies, given the disparities between these and those of the extant literature, which has almost exclusively been focused on the highly developed Western countries: in particular, United States, Germany, and United Kingdom.
Research activities in the GENIE project and around the State of CDR are in the process of providing a comprehensive knowledge base that is critical to advance this rapidly evolving research field. One of the key challenges right now for relevant research on CDR as well as evidence-based policy is the fact that information on developments in the sector are not centrally collected – similar to the situation for Renewables in the 1990s. Information remains highly dispersed, incomplete and largely unavailable limiting scientific progress and well-informed policy in the sector. In this context, the project actively also explores the role of AI in making this process efficient.
In this context GENIE has already contributed to filling critical knowledge gaps in climate policy. Most important to flag might be the that work bridges between IPCC scenarios and national greenhouse gas inventories marking a breakthrough achievement due to its direct applicability to a major science-policy process by providing a first satisfying effort to translate UNFCCC mitigation targets directly to modelled mitigation pathways. This critical knowledge gap had been highlighted in the UNFCCC process during the Global Stocktake.
Activities in the GENIE project also contributes to emerging discussions of how science assessments such as those by the Intergovernmental Panel on Climate Change can keep up with the exponentially growing evidence base by developing a new field on the use of artificial intelligence in the context of science assessments. The emergence of Chat-GPT and other large language models has been disruptive and future activities will focus on their potential to exploit new opportunities in this space.
The work on technology cost learning represents a significant contribution to the field of integrated assessment modeling systems by enhancing the analysis of technology dynamics. Conventionally, technological changes are treated as exogenous factors in IAMS. However, our approach introduces an endogenous consideration of these changes, enabling future analyses within IAMS to gain valuable insights into strategies aimed at expediting the adoption of innovative technologies for climate mitigation purposes
The technology upscaling database is the most comprehensive database of its type that we are aware of and will be invaluable for other researchers studying plausible rates of upscaling of different technologies relevant to climate change or other large global problems.
The SHARD methodology is the first attempt to bring methodological discipline into the selection of historical case studies, thus addressing an issue which has long been a problem and a source of criticism for this kind of research.

1.5 Describe the evolution and composition of each Principal Investigator's research team involved in the Synergy project.

• Principal Investigator 1

Prof. Benjamin Sovacool is PI of the project for Aarhus University and leads the qualitative social science aspects. He has led the research design and data collection for all phases at AU, and also served as coordinator for the entire GENIE project. In addition, he has served as lead author for a majority of GENIE publications, and hosted the in-person GENIE meeting in Herning and Aarhus, Denmark.
•Prof. Peter Enevoldsen: he is a co-investigator on the original GENIE project proposal. In the first half of the reporting period, he provided supervision and ensured access to necessary resources for the activities of GENIE, along with first-authoring one peer-reviewed article.
•Dr. Chad Baum: he joined the GENIE team as a postdoctoral researcher in May 2021. In the first half of the reporting period, together with Prof. B. Sovacool and Dr. S. Low, he conducted 125 expert interviews and co-authored 11 peer-reviewed publications. In the second half of the reporting period, he designed, implemented, and oversaw a cross-country set of surveys on public perceptions of CDR and SRM technologies across 30 countries, in 19 languages, and with a total of 30000-plus participants.
•Dr. Sean Low: he joined the GENIE team as postdoctoral researcher in May 2021. In the first half of the reporting period, together with Prof. B. Sovacool and Dr. C. Baum, he conducted 125 expert interviews and co-authored 11 peer-reviewed publications. In the second half of the reporting period, together with Dr. L. Fritz, he helped design and implement 44 focus groups on public perceptions of CDR and SRM technologies in 22 countries.
•Dr. Livia Fritz: she joined the GENIE team as postdoctoral researcher in September 2022. In the reporting period her work focused on the design and implementation of 44 focus groups on public perceptions of CDR and SRM technologies in 22 countries. She also provided support in the implementation of the cross-country survey.
•Dr. Gerardo de Rubens: though Dr. De Rubens was a co-investigator on the initial GENIE project proposal, he left his role at Aarhus University in December 2021.
•Emily Tynes: She maintains day-to-day administrative needs of the GENIE project to support ongoing research

• Principal Investigator 2

The GENIE team at MCC has been developing constantly since the project start. PI Jan Minx (40%), Felix Creutzig (10%), Sabine Fuss (10%) were part of the GENIE project from the beginning. Jan Minx as lead the quantitative social science, evidence synthesis, and machine learning aspects. In August 2021, Finn Müller-Hansen (50%; from March 2022 80%) joined at a postdoc working primarily on computational social science issues and public perceptions of CDR and geoengineering technologies as well as innovation dynamics in CDR. Sarah Lück joined as a post-doc with professional expertise in natural language processing (NLP) in December 2021 to work on the development of the machine-learning infrastructure as well as the living evidence mapping together. Tim Repke (24%) started contributing to the GENIE project in kind from October 2021, but only officially joined GENIE in January 2023. He leads on important aspects of the computational work and completes the team with expertise in computer science and NLP. William Lamb contributes as a post-doctoral researcher to the GENIE project since March 2022 with an emphasis on quantifying the CDR gap as well as residual emissions and designing new streams of work around the role of CDR in media and climate obstruction discourses. Quirina Rodriguez (65%) joined as a PhD student in September 2022. Her works focusses on CDR technologies in cities as well as using portfolio approaches in modelling CDR technologies and their scale-up. Together, Jan Minx, William Lamb, Sarah Lück, Finn Müller-Hansen, Sabine Fuss und Tim Repke contributed major parts oft he State of Carbon Dioxide Removal Report.

• Principal Investigator 3

The initial research team for WP4 was Greg Nemet, the Principal Investigator, and Cameron Roberts, a postdoc who was hired for the project. Since then, we have added two members to the research team. The first is Jenna Greene, PhD student who is leading the work on the technology upscaling database. The second is Ariana Hammersmith, a Master's student who is assisting with data collection.
Keywan Riahi is the PI for IIASA and his research team includes
-Elina Brutschin, Research Scholar
-Matthew Gidden, Senior Research Scholar (begin January 2021)
-Jan Steinhauser, Researcher
-Yoga Pratama, Research Scholar (begin August 2021)
-Volker Krey, Principal Research Scholar
-Oliver Fricko, Research Scholar
-Deepak Shah, Research Software Developer (begin January 2023)
-Daniel Huppmann, Senior Research Scholar
-Behnam Zakeri, Senior Research Scholar
-Marina Andrijevic, Research Scholar
Benjamin Mitterruntzer, Researcher (end March 2021)

1.6 Describe the Synergy aspects of the project, such as joint working arrangements, mobility of postdocs and students, common activities and exchange of methodologies for all teams involved in the Synergy project. If applicable, comment on emerging/transformative research and cross-fertilisation of scientific fields and connect them with key joint publications or any other output arising from the Synergy aspects.

The GENIE project team has taken a multi-pronged approach to developing synergies, exchanging ideas and collaborating on joint projects. First, we hold bi-annual in person project meetings that usually last 3 days. Second, we maintain regular contact through bi-monthly meetings and seminars. Third, we organize further in person interaction through research stays of the GENIE members at partner institutes. Fourth, we focus our activities around specific publication projects involving two or more project partners. And fifth, we organize headline publications and reports involving multiple institutes.
Concerning guest stays, Chad Baum, Cameron Roberts, and Jenna Greene have undertaken extended visits at IIASA. In 2024 Finn Müller-Hansen will join the UWISC for a three-month working stay, Livia Fritz will visit MCC, and Aarhus will also host MCC. These visits are focused on integrating survey insights into IAM activities, conducting novel analysis on the HATCH dataset, drawing from partner knowledge to further the historical analogue research, and to jointly work on innovation and scale-up dynamics in the CDR space. In particular Jenna Greene's on-going stay at IIASA for the Young Scientists Summer Program is focused on the parameterization of the technology cost learning and economies-of-scale module in MESSAGE, which requires information on learning and economies-of-scale, unit sizes, etc., that need to be estimated from historical data of the similar or analogous technology. Once completed, this will be a major advance in furthering the empirical foundations of integrated assessment modelling.
A number of integrative paper projects are currently underway between institutes. GENIE partners are developing research on synthetic meat, where UWISC, Aarhus and IIASA collaborated to establish realistic market uptake rates from multiple perspectives. This involved the analysis of historical analogues (UW-Madison) and the modelling of the land-use benefits of such scenarios (IIASA), including the potential for negative emissions. Aarhus and IIASA are undertaking an in-depth analysis of public perceptions and its impacts on the adoption of CDR technologies using the survey datasets. Overall, at least 3 teams are working together with at least 6 planned joint publications underway.
Finally, the State of CDR report has served as an important integrative element across the GENIE consortium. The first version published earlier this year contained chapters on the research landscape (led by MCC), innovation (UWISC), public perceptions (MCC), scenarios (IIASA), and the CDR gap (MCC), with many more contributions made by consortium members across the chapters and content. The second version currently in preparation will again drive our cross-institute collaborations and output.

Major challenges

Specify any major challenges, if any, you have encountered to date or anticipate in the near future related to the implementation of your research project, including any specific challenges linked to the implementation of the Synergy collaboration. Where appropriate, indicate any changes of direction you envisage.

2.1 Scientific challenges

Developing, designing, and implementing a survey format that can elicit public perceptions on unfamiliar technologies without unintentionally inducing prejudice or bias, examining ten technologies in the same survey, avoiding the risks of respondent, can be translated into almost 20 different languages and programmed into a desktop and handheld-device format (e.g., to encourage wide participation in countries with broader penetration of handheld devices and among segments of the population, specifically those younger in age), moreover, to do all of these with the aim of increasing representation of countries in the Global South when it comes to discussions of climate-intervention technologies. To date, countries from the Global South have only been included ten times in the extant literature; our large-scale survey exercise includes 11 such countries, thus exceeding the current total of the literature as a whole.

Developing, designing, and implementing a focus-group format that can elicit public perceptions and discussions on broadly unfamiliar technologies and doing so in a time-limited format (i.e., less than two hours), in order to limit respondent fatigue in light of the novelty of the topic. Such activities were conducted online and ensured the broad representation of actors across the globe, including in both rural and urban regions and many countries in the Global South – and also facilitated by the pre-dissemination of materials, along with explicit instructions for participants to consider them and discuss with friends and family.

The SHARD methodology discussed in section 2.4 has posed some research challenges in its implementation and dissemination. First, while our goal for the methodology was to facilitate fast, efficient historical case studies to provide quick advice to decisionmakers, in practice this has proven a challenge to achieve. This is due to the inherent realities of historical research. While we normally confine ourselves to secondary historical literature, often historical literature still takes a long time to read and fully digest. On topics that are of interest to many different historians (such as ammonia synthesis), there is often a large number of books, articles, and other sources available, which must be prioritized and in some cases read in their entirety.
Sorting out disagreements over the facts between different historians has also been a challenge, as has finding quantitative time series data going back far enough to cover long historical narratives. Ammonia synthesis, for example, did much of its early rapid upscaling in the 1920s—a time when data was collected in a very different way to how it is handled today. Reconciling old with new datasets to create a single set of time series required a considerable amount of work, and also some assumptions. To address these challenges, we are working on honing our process for reading and analyzing historical literature. For example, we are developing more efficient techniques for creating qualitative timelines in Microsoft Excel, which are very fast to consult during analysis and allow different historical accounts to be compared directly.
A final issue with SHARD has been in publication, where reviewers have at times been skeptical of our methodology. We are sometimes caught between the sustainability transition modelling community (who often prefer strictly quantitative analyses), and the history of technology or STS communities (who are skeptical of models, hard predictions, and direct one-for-one comparisons). Many of the criticisms raised by these groups are valid, but we emphasize that our methodology is meant to make some compromises between depth of analysis and time frames, to facilitate rapid and repeatable findings. This has usually been effective in getting articles accepted, provided that some rewriting is done to make these caveats clear in a way that satisfies a given set of reviewers.

2.2 Technical challenges

In a sense, conducting surveys in 19 different languages, including relevant programming of survey in both desktop and handheld-device format (together with professional survey firm, Norstat), to encourage as broad of representation and participation as possible as well as to minimize exclusion of particular groups + conducting focus groups online, in both urban and rural areas, in an online format and (frequently) conducted in a language other than English (together with Norstat)

Linking the integrated assessment models MAgPIE and MESSAGE was more time-intensive than expected as several model changes and associated tests were necessary in addition to a long range of tests to fine-tune settings between the models.
Building a state-of-the-art AI infrastructure is a time and resource-intensive and has delayed some of the scientific outputs slightly. The integration of OPEN-ALEX as the most comprehensive freely available catalogue of the world's scholarly scientific literature has posed a myriad of technical challenges that could be resolved by now. However, this has provided a unique text analysis machinery that will serve as the basis for fundamental scientific contributions in GENIE.
The technology upscaling database is time consuming and challenging due to the sheer volume of data that must be collected, sorted, categorized, and analyzed. It includes hundreds of separate time series, each of which had to be found somewhere in the extant historical data on various technologies and made consistent with the format of our database. Categorizing technologies according to technical characteristics has also been a challenge. To improve the robustness of this process, we have had the whole research team work on it, so that we can see where disagreements on categories occur and look more deeply into those cases. But this then requires fairly time-consuming work from all members of the research team and holds up progress until everyone has found time to complete this task. We are addressing this issue by developing more efficient, and sometimes automated, techniques for working with the database. Nevertheless, this issue has slowed down our publishing based on this research.

2.3 Issues related to the support provided by the Host Institution (Start-up facilities, working space, access to labs, equipment, resources, etc.)

AU: The relationship between the research team and the Host Institution (Aarhus University) has been excellent and all the provisions of the Supplementary Agreement have been respected.
MCC: The relationship and the communication between the PI and the Host Institution has been very good. The HI administration supports the PI with the general project management providing the support in Personnel/Human Resources, Financial administration, procurements, travel assistance, etc. as well as gives the advices on technical aspects of ERC regulations and guidelines. All the provisions of the Supplementary Agreement have been respected.
UWISC: We have no issues to raise relating to our host institution, which has been quite supportive of our work and gives us good working space.
IIASA: The IIASA PI and research team have no issues working with their Host Institution, which has been supportive in the execution of the grant.

2.4 Other

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Research expeditions

List of expeditions		
Period (start-end)	**Place**	**Purpose**
08/08/2021 - 14/08/2021	*MCC*	*Greg Nement from UWISC research stay at MCC*
26/03/2023 - 01/04/2023	*MCC*	*Greg Nemet from UWISC to MCC for research stay*
12/09/2021 - 18/09/2021	*IIASA*	*Gregory Nemet to IIASA for research stay*
04/06/2023 - 10/06/2023	*IIASA*	*Cameron Roberts to IIASA for research stay*
15/01/2023 - 21/01/2023	*IIASA*	*Gregory Nemet to IIASA for research stay*
08/05/2022 - 14/05/2022	*MCC*	*Cameron Roberts to MCC for research stay*
01/03/2023 - 31/03/2023	*Maine, USA*	*Site visit to Running Tides (start-up working on marine biomass as a carbon-removal solution)*
18/09/2022 - 24/09/2022	*IIASA*	*Gregory Nemet to IIASA for research stay*
01/06/2022 - 30/06/2022	*Ecuador*	*Site visit of afforestation, reforestation, and mangrove restoration in western Ecuador*
09/01/2022 - 15/01/2022	*IIASA*	*Gregory Nemet to IIASA for research stay*
01/03/2023 - 31/03/2023	*United Kingdom (Wales, Scotland)*	*Site visit to start-ups and field trials on seagrass restoration*
06/11/2022 - 12/11/2022	*IIASA*	*Cameron Roberts to IIASA for research stay*
01/07/2021 - 31/07/2021	*Greenland*	*Site visit investigating ice protection in Western Greenland on the Greenland Ice Sheet near Kangerlussuaq*
06/03/2022 - 12/03/2022	*IIASA*	*Gregory Nemet to IIASA for research stay*
01/10/2021 - 31/10/2022	*British Columbia, Canada*	*Site visit to Carbon Engineering (start-up working on direct air capture)*
07/11/2021 - 13/11/2021	*IIASA*	*Gregory Nemet to IIASA for research stay*
01/11/2022 - 30/11/2022	*IIASA (Vienna, Austria)*	*Collaboration with IIASA Partners on integrating survey insights into IAM activities*
01/06/2023 - 31/08/2023	*IIASA*	*Jenna Greene to IIASA for PhD research stay*
01/10/2022 - 31/10/2022	*North Queensland, Australia*	*Site visits to Reef Restoration and Adaptation Program (RRAP) and other venues involving climate-intervention technologies of marine cloud brightening, biochar, and enhanced weathering*
30/10/2022 - 05/11/2022	*AU*	*Cameron Roberts to Aarhus University for research stay*
01/09/2021 - 30/09/2022	*Iceland*	*Site visit of the Climeworks Orca Direct Air Capture facility at Hellisheiði Iceland*

Awards and recognitions

List of awards and recognitions						
No.	**Award type**	**Title of award**	**Recipient of award**	**Year**	**Reason the award was made (if applicable)**	**Any further information / clarifications**

Dissemination of results to academic and non-academic audience that you would like to highlight

List of disseminations								
No.	**Type of activities**	**Main Leader**	**Title**	**Date**	**Place**	**Type of audience**	**Size of audience**	**Countries addressed**
1	*Participation to a Workshop*	*Jan Steinhauser*	*"Land Use Model MAgPIE Linkage to MESSAGEix" at MESSAGEix Community Workshop*	*24/05/2023*	*Laxenburg, Austria*	*Scientific Community (Higher Education, Research)*	*80*	*AT - Austria*
2	*Other*	*Chad M. Baum*	*Interview on Space-based Geoengineering*	*18/10/2022*	*Times of London*	*General Public*	*15*	*UK - United Kingdom*
3	*Participation to an Event other than a Conference or a Workshop*	*Chad M. Baum*	*GENIE Project: Societal and Economic Implications of Geoengineering and Negative-Emissions Technologies*	*13/10/2022*	*Queensland University of Technology*	*Scientific Community (Higher Education, Research)*	*25*	*AU - Australia*
4	*Participation to a Workshop*	*Jan Steinhauser*	*"Soft-linking MAgPIE and MESSAGE" at MAgPIE Stories Workshop*	*15/03/2022*	*Online*	*Scientific Community (Higher Education, Research)*	*40*	*AT - Austria*
5	*Participation to a Conference*	*Greg Nemet*	*Scale up rates in historical technologies*	*01/06/2022*	*Gothenburg Sweden*	*Industry*	*500*	*SE - Sweden*
6	*Participation to a Conference*	*Greg Nemet*	*State of CDR at Climeworks DAC Summit*	*01/06/2023*	*Zurich*	*Industry*	*2500*	*US - United States DE - Germany*
7	*Other*	*Chad M. Baum*	*Interview on Space-based Geoengineering*	*08/02/2023*	*Washington Post*	*General Public*	*63*	*US - United States*
8	*Communication Campaign (e.g. Radio, TV)*	*Greg Nemet*	*State of CDR release*	*01/01/2023*	*Online*	*Other*	*1000*	*US - United States*

9	*Participation to a Conference*	*William Lamb*	*“The carbon dioxide removal gap: current removals and country proposals versus future requirements for limiting warming to 2° C or lower” at EGU 2023*	*25/04/2023*	*EGU 2023, Vienna, Austria*	*Scientific Community (Higher Education, Research)*	*40*	*AT - Austria*
10	*Participation to a Workshop*	*Jan Minx*	*The State of Carbon Dioxide Removal*	*13/04/2023*	*Basel*	*Industry*	*200*	*CH - Switzerland DE - Germany FR - France UK - United Kingdom DK - Denmark AT - Austria*
11	*Participation to a Workshop*	*Jan Minx*	*The State of CDR: A Global Status Report and Data Platform*	*17/06/2022*	*Gothenburg*	*Scientific Community (Higher Education, Research)*	*100*	*SE - Sweden*
12	*Participation to a Conference*	*Sarah Lück*	*Governance of Carbon Dioxide Removal*	*21/10/2022*	*Canada, virtual*	*Scientific Community (Higher Education, Research)*	*20*	*CA - Canada*
13	*Press release*	*Jan Minx*	*The State of Carbon Dioxide Removal*	*17/01/2023*	*Online*	*Media*	*15*	*UK - United Kingdom*
14	*Other*	*Jan Minx*	*CO2 Entnahme methoden: ein Überblick*	*07/03/2023*	*Berlin*	*Policy Makers*	*50*	*DE - Germany*
15	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*The role and state of CDR in climate policy*	*20/04/2023*	*Berlin*	*Industry*	*40*	*DE - Germany UK - United Kingdom DK - Denmark FR - France IT - Italy*
16	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*Negative Emissions*	*25/08/2022*	*Potsdam*	*Scientific Community (Higher Education, Research)*	*50*	*DE - Germany*
17	*Press release*	*Gregory Nemet*	*The State of Carbon Dioxide Removal*	*18/01/2023*	*Online*	*Media*	*20*	*AU - Australia NZ - New Zealand*

18	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*The State of CDR*	*14/03/2023*	*Online*	*Industry*	*20*	*DE - Germany AT - Austria DK - Denmark UK - United Kingdom FR - France IT - Italy*
19	*Participation to a Conference*	*Sarah Lück Lück*	*A living map of CDR*	*16/06/2022*	*Gothenburg*	*Scientific Community (Higher Education, Research)*	*40*	*SE - Sweden*
20	*Participation to a Conference*	*Jan Steinhauser*	*“Land Use Model MAgPIE Linkage to MESSAGEix” at MESSAGEix Community Workshop*	*24/05/2023*	*Laxenburg, Austria*	*Scientific Community (Higher Education, Research)*	*80*	*AT - Austria*
21	*Participation to a Workshop*	*Jan Minx*	*Methoden der CO2 Entnahme: Funktionsweise und Entwicklungsstand*	*20/02/2023*	*Berlin*	*Policy Makers*	*150*	*DE - Germany*
22	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*The State of Carbon Dioxide Removal*	*28/06/2023*	*IIASA*	*Scientific Community (Higher Education, Research)*	*50*	*DK - Denmark AT - Austria US - United States DE - Germany*
23	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*The role and state of CDR*	*02/02/2023*	*Berlin*	*Industry*	*30*	*DE - Germany*
24	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*The State of CDR*	*17/04/2023*	*Berlin*	*Policy Makers*	*20*	*DE - Germany*
25	*Participation to a Conference*	*Jan Minx*	*The state and future of CDR*	*20/02/2023*	*Potsdam*	*Scientific Community (Higher Education, Research)*	*400*	*DE - Germany*
26	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*The State of Carbon Dioxide Removal: implications for Germany*	*30/03/2023*	*Berlin*	*Civil Society*	*10*	*DE - Germany*

27	*Press release*	*Jan Minx*	*Deutschland braucht einen Plan für negative Emissionen*	*20/06/2022*	*Frankfurter Allgemeine Zeitung*	*General Public*	*740000*	*DE - Germany*
28	*Press release*	*Jan Minx*	*The State of Carbon Dioxide Removal*	*17/01/2023*	*virtual*	*Media*	*50*	*DE - Germany*
29	*Participation to a Conference*	*Jan Minx*	*A data science revolution for synthesizing scenario evidence in IPCC assessments*	*20/06/2022*	*Laxenburg/ IIASA*	*Scientific Community (Higher Education, Research)*	*300*	*AT - Austria*
30	*Participation to a Conference*	*Tim Repke*	*eoengineering on Twitter: Analysing sentiments, emotions emotions, and conspiracies about controversial technologies*	*15/06/2022*	*Gothenburg*	*Scientific Community (Higher Education, Research)*	*100*	*SE - Sweden*
31	*Participation to an Event other than a Conference or a Workshop*	*Jan Minx*	*The State of Carbon Dioxide Removal*	*19/01/2023*	*virtual*	*Other*	*500*	*DE - Germany US - United States*
32	*Communication Campaign (e.g. Radio, TV)*	*Chad M. Baum*	*Interview on Space-based Geoengineering*	*02/06/2022*	*Reviewer 2 Does Geoengineering Podcast*	*Scientific Community (Higher Education, Research)*	*50100*	*US - United States*
33	*Participation to an Event other than a Conference or a Workshop*	*Jan Steinhauser*	*“Soft-linking MAgPIE and MESSAGE” at MAgPIE Stories Workshop*	*15/05/2022*	*Online*	*Scientific Community (Higher Education, Research)*	*40*	*DE - Germany*
34	*Participation to a Conference*	*Jan Minx*	*The State of Carbon Dioxide Removal: A Global Status Report & Data Platform that can benefit the scenarios process*	*20/06/2022*	*Laxenburg/ IIASA*	*Scientific Community (Higher Education, Research)*	*300*	*AT - Austria*

35	*Participation to a Workshop*	*Benjamin Sovacool*	*Anticipating Future Debates on Climate Intervention*	*15/03/2023*	*Lawrence Livermore National Laboratory*	*Scientific Community (Higher Education, Research)*	*100*	*US - United States*
36	*Participation to a Conference*	*Matt Gidden*	*“The role of carbon removals for net zero emissions” at ISCC Global Sustainability Conference*	*15/02/2023*	*Brussels, Belgium*	*Scientific Community (Higher Education, Research)*	*100*	*BE - Belgium*
37	*Participation to a Workshop*	*Elina Brutschin*	*Presentation at “State of science of political futures” workshop*	*24/10/2022*	*Bonn, Germany*	*Scientific Community (Higher Education, Research)*	*40*	*DE - Germany*
38	*Participation to a Workshop*	*Yoga Pratama*	*“Technology cost learning & recursive dynamic implementation in MESSAGEix” at MESSAGEix Community Workshop*	*24/05/2023*	*Laxenburg, Austria*	*Scientific Community (Higher Education, Research)*	*80*	*AT - Austria*
39	*Other*	*Chad M. Baum*	*Interview on Space-based Geoengineering*	*02/02/2023*	*New Scientist*	*General Public*	*1000*	*US - United States*
40	*Participation to a Workshop*	*Florian Maczek*	*“MESSAGEix-Materials: Integrated assessment of emission mitigation scenarios in the petrochemical sector” at MESSAGEix Community Workshop*	*24/05/2023*	*Laxenburg, Austria*	*Scientific Community (Higher Education, Research)*	*80*	*AT - Austria*
41	*Participation to a Conference*	*Matt Gidden*	*“Fairness and feasibility in deep mitigation pathways using engineered carbon removals” at IAMC 2022*	*29/11/2022*	*IAMC 2022, College Park, MD, USA*	*Scientific Community (Higher Education, Research)*	*1000*	*US - United States*

42	*Participation to a Conference*	*Matt Gidden*	*“Policy implications from aligning IPCC scenarios to national land emissions inventories” at EGU 2023*	*23/04/2023*	*EGU 2023, Vienna, Austria*	*Scientific Community (Higher Education, Research)*	*40*	*AT - Austria*

Information on other important outputs that have arisen from this project (such as software, databases, exhibitions or other types of outputs).

List of other outputs
IIASA has produced an initial version of the GENIE Hub at https://iiasa.ac.at/projects/genie, highlighting a large number of GENIE-related research outputs as well as a GENIE Scenario Explorer, housing the scenario data used in “Fairness and feasibility in deep mitigation pathways using engineered carbon removals”, the HATCH database, and the first-of-a-kind data related to aligning IPCC-assessed scenarios with UNFCCC National Greenhouse Gas Inventories (currently private until paper is accepted), among others. Right now, MCC is developing the web-interface to provide an interactive resource that can be used by the wider community. The AI pipeline will be used to develop other lines of living evidence for CDR and SRM technologies. UWISC has developed Historical Adoption of TeCHnologies (HATCH) dataset as part of their database of technological upscaling rates.

List of free keywords

Geoengineering, GENIE, Climate Change, Climate Policy, DAC, Direct Air Capture, Carbon, CDR, Carbon Dioxide Removal

1. PUBLISHABLE SUMMARY

Summary of the context and overall objectives of the project (For the final period, include the conclusions of the action)

The path to climate neutrality needs to explicitly consider the roles of solar geoengineering and negative emissions technologies. A meta-analytical framework where social science, engineering, and physical science disciplines merge is necessary for a comprehensive mapping of this transition. The EU-funded GENIE project will explore the environmental, technical, social, legal, ethical and policy dimensions of greenhouse gas removal and solar radiation management. GENIE aims to produce a comprehensive scientific assessment for evidence-based policymaking to address climate change, and to expand our toolkit for a zero-emissions future.

Geoengineering technologies, such as solar radiation management (SRM), and negative emissions technologies, such as greenhouse gas removal (GGR), are emerging options to address climate change. This project will investigate the environmental, technical, social, legal, and policy dimensions of GGR and SRM. We provide an urgently needed interdisciplinary and holistic perspective of these technologies in order to understand conditions under which they might be deployed at scale. Our meta-analytical framework integrates insights from social science, engineering and physical science disciplines to provide a comprehensive view of GGR and SRM in the transition to climate neutrality in Europe and the world. The project will conduct excellent research and generate a robust, scientific assessment for evidence-based policymaking. Our research framework consists of three pillars—techno-economic systems, socio-technical systems, and systems of political action—within which we place six work packages (WPs). These are: (1) Understanding the current state and future potential of GGR and SRM technologies in terms of their technical and economic features; (2) Analysing bottlenecks in transitions to climate neutrality and their implications for deployment; (3) Identifying social acceptance and legitimacy constraints, (4) Learning, diffusion, and adoption; (5) Implications for Sustainable Development Goals of archetypical mitigation pathways; and 6) Policy options and governance. A crosscutting WP7 synthesizes research along three salient, but under-researched themes: A) Socio-technical change; B) Managing transition risks; and C) Political economy and feasibility of deployment. WP8 focuses on stakeholder engagement, entailing scenario co-design, science-policy dialogue formats, and specific outreach formats for target groups.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far (For the final period please include an overview of the results and their exploitation and dissemination)

During this first scientific reporting period of the GENIE project, many results have been made towards the goal of the GENIE project.
The GENIE team at Aarhus University has conducted 125 expert interviews, a large scale survey covering 30 countries, and 44 focus groups in 22 countries. These were conducted to ensure that the Global South was represented at a level that is broader than the entire existing literature on climate intervention technologies. The team has also conducted site visits in Australia, Canada, Ecuador, Greenland, UK, and the US.
IIASA has had several notable publications including “Policy guidance and pitfalls aligning IPCC scenarios to national land emissions inventories”, which for the first-time gross negative and positive land-use emissions pathways have been developed. IIASA has also focused on key modelling improvements in areas of technology granularity and better representation of governance needs for

CDR and climate projections. IIASA has also launched a prototype for the GENIE Hub, which will act as a way to disseminate GENIE research and knowledge.
MCC has been a major contributor to "The State of Carbon Dioxide Removal" which has filled a critical gap by establishing a new flagship science assessment in the space of carbon dioxide removal (CDR) that has previously been missing.

UWISC has primarily been working on quantitative effort to measure rates of upscaling in 166 historical technologies, across multiple different national contexts. In addition to this, UWISC has also been working on deeper, slower, qualitative approach which uses a structured process of historical analogue research to look in detail at the factors affecting the upscaling rate of comparable historical technologies, as well as the risks and challenges that these technologies faced and the extent to which these might affect CDR and SRM technologies in the future.

Progress beyond the state of the art and expected results until the end of the project

W are beyond the state of the art in terms of our meta-theoretical framework, and our reliance on a huge swathe of mixed-methods data so far. This includes:
• Expert elicitation exercise and opinion survey (N=74)
• Semi-structured expert research interviews (N=125)
• Site visits and naturalistic observation (N=8 so far, and growing, with supplemental research interviews onsite)
o July 2021: ice protection in Western Greenland on the Greenland Ice Sheet near Kangerlussuaq
o September 2021: the Climeworks Orca Direct Air Capture facility at Hellisheiði Iceland
o April 2022: The Drax BECCS facility near the Humber, England
o June 2022: afforestation, reforestation, and mangrove restoration in western Ecuador
o October 2022: the Carbon Engineering Direct Air Capture facility at Squamish Canada
o October 2022: marine cloud brightening, coral reef fogging and shading, enhanced weathering, biochar, and ecosystem adaptation and restoration in eastern (tropical) Australia
o March 2023: seagrass restoration and marine carbon removal in Wales (UK)
o March 2023: Running Tide, seaweed planting, kelp, blue carbon, carbon boys, ocean alkalinization, but also some coastal protection and beach nourishment in Maine, USA
• The survey (n=30,284 respondents, across 19 languages in 30 countries)
• Focus groups (N=323 respondents across 44 focus groups in 22 countries)
• Historical analogues and case studies across 10 technologies
• Systematic reviews and the State of CDR report
• Refined IAM modeling concerning DACCS and BECCS via IIASA and the Message-ix platform

In terms of tasks to the end of the project, we still have many, we have mapped out a remaining 20+ tasks across all 8 WPs which will take us until the end of the project.

Address (URL) of the project's public website

https://genie-erc.github.io

3. DELIVERABLES

Del. no.	Deliverable name	WP no.	Lead beneficiary	Type	Dissemin. level	Delivery date from Annex I (prj month)	Actual delivery date	Revised due date	Status	Comments
D1.1	Data Management Plan (DMP)	WP1	AARHUS UNIVERSITET	ORDP: Open Research Data Pilot	Confidential, only for members of the consortium (including the Commission Services)	6	13 January 2023	31 January 2022	SUBMITTED	
D2.1	H - Requirement No. 3	WP2	AARHUS UNIVERSITET	Ethics	Confidential, only for members of the consortium (including the Commission Services)	6	22 April 2022	31 January 2022	ACCEPTED	
D2.2	H - Requirement No. 6	WP2	AARHUS UNIVERSITET	Ethics	Confidential, only for members of the consortium (including the Commission Services)	6	20 May 2022	31 January 2022	ACCEPTED	
D2.3	POPD - Requirement No. 14	WP2	AARHUS UNIVERSITET	Ethics	Confidential, only for members of the consortium (including the	6	26 January 2023	31 October 2022	ACCEPTED	

Del. no.	Deliverable name	WP no.	Lead beneficiary	Type	Dissemin. level	Delivery date from Annex I (prj month)	Actual delivery date	Revised due date	Status	Comments
					Commission Services)					
D2.4	NEC - Requirement No. 17	WP2	AARHUS UNIVERSITET	Ethics	Confidential, only for members of the consortium (including the Commission Services)	6	20 May 2022	31 January 2022	ACCEPTED	
D2.5	M - Requirement No. 18	WP2	AARHUS UNIVERSITET	Ethics	Confidential, only for members of the consortium (including the Commission Services)	6	20 May 2022	31 January 2022	ACCEPTED	
D2.6	GEN - Requirement No. 19	WP2	AARHUS UNIVERSITET	Ethics	Confidential, only for members of the consortium (including the Commission Services)	18	31 October 2022	2 December 2024	NOT SUBMITTED	

General Remarks

3. Dissemination and exploitation of results

3.1 Scientific publications

Type of scientific publication	Title of the scientific publication	DOI	ISSN or eSSN	Authors	Title of the journal or equivalent	Number, date	Publisher	Place of publication	Year of publication	Relevant pages	Public & private publication (1)	Peer-review	Is/Will open access provided to this publication	Project team members in authors list
Article in Journal	*Decision makers need constantly updated evidence synthesis*	*10.1038/d41586-021-03690-1*	*0028-0836*	*Julian Elliott, Rebecca Lawrence, Jan C. Minx, Olufemi T. Oladapo, Philippe Ravaud, Britta Tendal Jeppesen, James Thomas, Tari Turner, Per Olav Vandvik & Jeremy M. Grimshaw*	*Nature*	*2021.12.16*	*Nature Publishing Group*	*United Kingdom*	*2021*		*No*	*No*	*Yes - available in Gold Open Access*	*Jan C. Minx*
Article in Journal	*Machine-learning-based evidence and attribution mapping of 100,000 climate impact studies*	*10.1038/s41558-021-01168-6*	*1758-678X*	*Max Callaghan, Carl-Friedrich Schleussner, Shruti Nath, Quentin Lejeune, Thomas R. Knutson, Markus Reichstein, Gerrit Hansen, Emily Theokritoff, Marina Andrijevic, Robert J. Brecha, Michael Hegarty, Chelsea Jones, Kaylin Lee, Agathe Lucas, Nicole van Maanen, Inga Menke, Peter Pfleiderer, Burcu Yesil, Jan C. Minx*	*Nature Climate Change*	*2021.10.11*	*Nature Publishing Group*	*United Kingdom*	*2021*		*No*	*Yes*	*No*	*Jan C. Minx*

Article in Journal	*Between the sun and us: Expert perceptions on the innovation, policy, and deep uncertainties of space-based solar geoengineering*	*10.1016/j.rser.2022.112179*	*1364-0321*	*Baum, Chad M.; Low, Sean; Sovacool, Benjamin K; Global Sustainability Governance; Environmental Governance*	*Renewable and Sustainable Energy Reviews*		*Elsevier BV*	*Netherlands*	*2022*		*No*	*Yes*	*Yes - available in Gold Open Access*	*Baum, Chad M., Low, Sean*
Article in Journal	*Reckless or righteous? Reviewing the sociotechnical benefits and risks of climate change geoengineering*	*10.1016/j.esr.2021.100656*	*2211-467X*	*Benjamin K. Sovacool*	*Energy Strategy Reviews*		*Elsevier*	*Netherlands*	*2021*		*No*	*Yes*	*Yes - available in Gold Open Access*	
Article in Journal	*Climate policy for a net-zero future: ten recommendations for Direct Air Capture*	*10.1088/1748-9326/ac77a4*	*1748-9326*	*Sovacool, Benjamin K; Baum, Chad M.; Low, Sean; Roberts, Cameron; Steinhauser, Jan; Global Sustainability Governance; Environmental Governance*	*Environmental Research Letters*		*Institute of Physics Publishing*	*United Kingdom*	*2022*		*No*	*Yes*	*Yes - available in Gold Open Access*	*Baum, Chad M.; Low, Sean; Roberts, Cameron; Steinhauser, Jan*
Article in Journal	*Navigating Potential Hype and Opportunity in Governing Marine Carbon Removal*	*10.3389/fclim.2021.664456*	*2624-9553*	*Boettcher Miranda, Brent Kerryn, Buck Holly Jean, Low Sean, McLaren Duncan, Mengis Nadine*	*Frontiers in Climate*		*Frontiers*	*Lausanne*	*2021*		*No*	*Yes*	*Yes - available in Gold Open Access*	*Low Sean*
Article in Journal	*Risk–risk governance in a low-carbon future: Exploring institutional, technological, and behavioral tradeoffs in climate geoengineering pathways*	*10.1111/risa.13932*	*0272-4332*	*Sovacool Benjamin K., Baum Chad M., Low Sean*	*Risk Analysis*		*Blackwell Publishing Inc.*	*United Kingdom*	*2022*		*No*	*Yes*	*Yes - available in Gold Open Access*	*Baum Chad M., Low Sean*

Article in Journal	Rethinking Net-Zero systems, spaces, and societies: “Hard” versus “soft” alternatives for nature-based and engineered carbon removal	10.1016/j.gloenvcha.2022.102530	0959-3780	Sean Low, Chad M. Baum, Benjamin K. Sovacool	Global Environmental Change		Elsevier BV	Netherlands	2022		No	Yes	Yes - available in Gold Open Access	Sean Low, Chad M. Baum
Article in Journal	Taking it outside: Exploring social opposition to 21 early-stage experiments in radical climate interventions	10.1016/j.erss.2022.102594	2214-6296	Sean Low, Chad M. Baum, Benjamin K. Sovacool	Energy Research & Social Science		Elsevier Limited	United Kingdom	2022		No	Yes	Yes - available in Gold Open Access	Sean Low, Chad M. Baum
Article in Journal	Climate protection or privilege? A whole systems justice milieu of twenty negative emissions and solar geoengineering technologies	10.1016/j.polgeo.2022.102702	0962-6298	Benjamin K. Sovacool, Chad M. Baum, Sean Low	Political Geography		Pergamon Press Ltd.	United Kingdom	2022		No	Yes	Yes - available in Gold Open Access	Chad M. Baum, Sean Low
Article in Journal	Undone science in climate interventions: Contrasting and contesting anticipatory assessments by expert networks	10.1016/j.envsci.2022.08.026	1462-9011	Sean Low, Chad M. Baum, Benjamin K. Sovacool	Environmental Science & Policy		Elsevier BV	Netherlands	2022		No	Yes	Yes - available in Gold Open Access	Sean Low, Chad M. Baum
Article in Journal	Determining our climate policy future: expert opinions about negative emissions and solar radiation management pathways	10.1007/s11027-022-10030-9	1381-2386	Sovacool Benjamin K., Baum Chad M., Low, Sean	Mitigation and adaptation strategies for global change		Kluwer Academic Publishers	Netherlands	2022		No	Yes	Yes - available in Gold Open Access	Baum Chad M., Low, Sean
Article in Journal	Beyond climate stabilization: Exploring the perceived sociotechnical co-impacts of carbon removal and solar geoengineering	10.1016/j.ecolecon.2022.107648	0921-8009	Sovacool Benjamin K., Baum Chad M., Low Sean	Ecological Economics		Elsevier BV	Netherlands	2023		No	Yes	Yes - available in Gold Open Access	Baum Chad M., Low Sean

Article in Journal	*Exploring Enablers for an Ambitious Coal Phaseout*	*10.17645/pag.v10i3.5535*	*2183-2463*	*Elina Brutschin; Felix Schenuit; Bas Van Ruijven; Keywan Riahi*	*Politics and Governance*	*10, 3*	*Cogitatio Press*	*Lisbon*	*2022*		*No*	*Yes*	*Yes - available in Gold Open Access*	*Elina Brutschin*
Other	*The State of Carbon Dioxide Removal*	*10.17605/osf.io/w3b4z*		*Stephen Smith, Oliver Geden, Gregory Nemet, Matthew Gidden, Wlliam Lamb, Carter Powis, Rob Bellamy, Max Callaghan, Annette Cowie, Emily Cox, Sabine Fuss, Thomas Gasser, Giacomo Grassi, Jenna Greene, Sarah Lück, Aniruddh Mohan, Finn Müller-Hansen, Glen Peters, Yoga Pratama, Tim Repke, Keywan Riahi, Felix Schenuit, Jan Steinhauser, Jessica Strefler, Jose Valenzuela, Jan Minx*		*1st Edition*	*Sate of Carbon Dioxide Removal Consortium*	*Oxford*	*2023*	*https://www.stateofcdr.org/*	*Yes*	*Yes*	*Yes - available in Gold Open Access*	*Gregory Nemet, Matthew Gidden, Wlliam Lamb, Sabine Fuss, Thomas Gasser, Jenna Greene, Sarah Lück, Finn Müller-Hansen, Yoga Pratama, Tim Repke, Jan Steinhauser,*

1 "Both the joint publications coming from academic and corporate project participants as well as joint publications of project participants with academic/corporate organisations outside the consortium (as long as they are related to the funded project) should be reported."

3.2 Intellectual property rights resulting from the project

Type of IP Rights	Official title of the application	Application reference	Date of the application	Applicant(s)	Has the IPR protection been awarded?	If available, official publication number of award of protection

4. Open Research Data

More information on Data Management Plans (DMPs) in the Online Manual.

Digital Object Identifier, DOI (if available)	Title/Identifier (if no DOI available)	Is this dataset Openly accessible[1]?	Is this dataset re-usable[2]	If the dataset is linked to a publication, specify the DOI of the publication

[1] Accessible means Open Access defined as free of charge access for anyone via Internet. Answer "yes" if the open access to the data is already established or if it will be established after an embargo period.

[2] Re-usability has 2 aspects: 1) technical: the technical standards used are compatible 2) legal: the necessary rights are in place for other users to use the dataset.