Fighting climate change requires an assessment of all options

Benjamin Sovacool, Aarhus University and Sussex University
Keywan Riahi, International Institute on Applied Systems Analysis
Jan Minx, Mercator Research Institute on Global Commons and Climate Change (MCC)
Gregory Nemet, University of Wisconsin

"We have very little time to achieve the goals set in the Paris Agreement, and climate impacts, such as increased heat, droughts, or flooding, occur more often and are more severe. Thus now is the time to expand the solution space and to assess all available options to transform the system and evaluate their risks."

Keywan Riahi
International Institute of Applied Systems Analysis.

In the UN Paris Agreement in 2015, more than 190 countries committed to hold global warming well below 2°C, and pursue limiting it even to 1.5°C compared to pre-industrial levels. More than half of the global emitters have announced targets to achieve a climate-neutral world by the middle of the century.

Yet, global greenhouse gas emissions have continued to rise (Friedlingstein *et al.*, 2020). Climate change policy does not reflect the ambition of the Paris targets. However, it may already be too late to legislate ourselves out of climate change, and investment in sustainable energy sources is happening too slowly to put us on a pathway to climate neutrality.

Further, there are multiple indications that future climate impacts have been underestimated and could involve non-trivial "tipping points" (Xu *et al.*, 2018). Given the risk of climate catastrophe, and that the required pace of energy transitions to reach the 2°C or 1.5°C targets are beyond historical experience, new unconventional solutions must be considered, and their implications carefully assessed.

Unconventional climate engineering solutions

Negative emissions options such as greenhouse gas removal (GGR) will need to feature in net zero strategies by removing greenhouse gases from the atmosphere and storing it safely in biological or geological sinks. Potential methods include bioenergy with carbon capture and storage (BECCS), afforestation, as well as direct air capture and CO_2 utilisation, among others (Smith *et al.*, 2015; Minx *et al.*, 2018; Griscom *et al.*, 2018; Low and Schäfer, 2020; Hepburn *et al.*, 2019).

There are three reasons why GGR needs to be considered a crucial complement of climate change mitigation. First, GGR will need to compensate for greenhouse gas emissions that are hard to avoid, such as methane emissions from cows and other ruminating animals, nitrogen emissions from fertiliser use, or certain carbon emissions in the industrial sector. Without compensating GGR technologies, it is very unlikely that we can succeed in fully decarbonising human activity (Minx *et al.*, 2018).

Second, GGR can help accelerate decarbonisation, complementing climate policies that aim at structural changes of the current systems.

Finally, global net removal of greenhouse gas emissions from the atmosphere is important as a long-term risk-management option that may help reverse some of the climate impacts if we find out that we have surpassed critical climate thresholds. (Minx *et al.*, 2018).

The idea behind both GGR and SRM is that they could buy some time for the required transition process, e.g. by allowing for a temporary overshoot of the remaining carbon budget. This

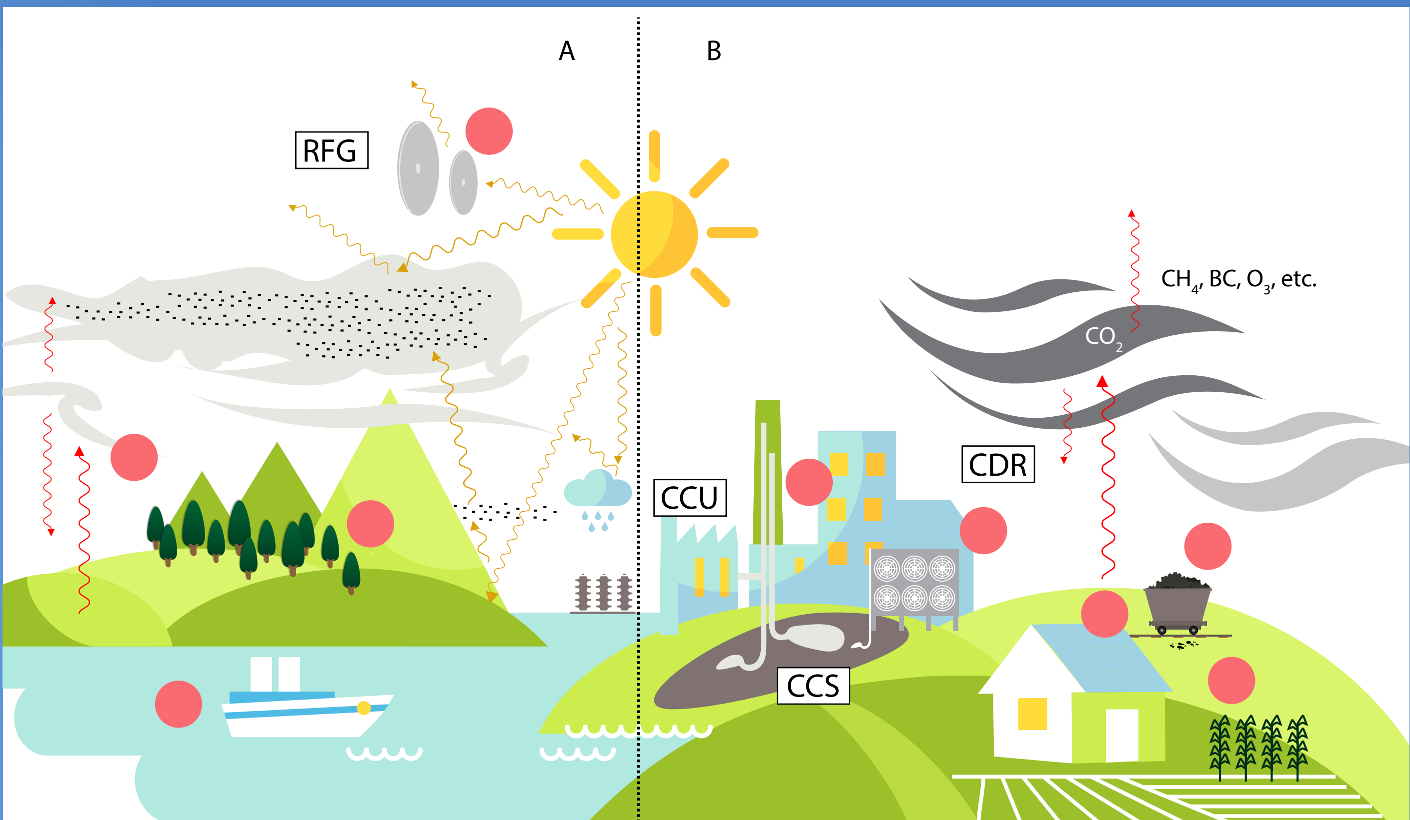

Figure 1: A visualisation of climate options across carbon capture and storage, greenhouse gas removal and solar radiation management. (A) Five unique solar radiation technologies, or radiative forcing geoengineering (RFG). (B) Carbon capture and utilisation (CCU) and carbon capture and storage (CCS) technologies— CH_4 = methane, BC = black carbon, O_3 = ozone. Seven distinct carbon dioxide removal (CDR) options.

"carbon debt" can be paid back later via net negative emissions, i.e. a net removal of greenhouse gas emissions from the atmosphere (Minx *et al.*, 2018).

More controversially, methods for increasing the Earth's albedo, known as solar radiation management (SRM), have also been proposed as emergency options when global temperatures need to be temporarily limited (National Research Council, 2015a and 2015b). Prominent examples include cirrus cloud thinning, marine cloud brightening, and stratospheric aerosol injection (National Academies of Sciences, Engineering, and Medicine, 2021).

Nevertheless, deep uncertainties around the physical science basis in climate change and tipping points in the Earth system may require emergency climate engineering options that would work on shorter time scales than the decades involved in fully decarbonising the world economy (IPCC, 2014; Lenton *et al.*, 2008; Kriegler *et al.*, 2009).

Despite their importance, most research on GGR and SRM remains technical rather than social (Minx *et al.*, 2017). Existing GGR and SRM options are changing rapidly in terms of their technical design, cost, performance, scalability, and deployment potential.

SRM technologies are at an early stage of development—current knowledge is mainly derived from atmospheric modelling studies (Kravitz *et al.*, 2017; Irvine *et al.*, 2017). The role of SRM in climate change mitigation portfolios is still poorly understood (Tavoni *et al.*, 2017), and its effects on temperature, precipitation, and ecosystems, especially at the sub-global level, remain difficult to assess (Kravitz and MacMartin, 2020). Even though the need for research on broader sustainability implications of GGR and SRM have been iterated in the literature (Fuss *et al.*, 2016), this research gap is still wide open.

"We're not just interested in the technologies themselves. We want to examine everything around them. From political attitudes, investment and innovation opportunities, to social aspects and risk profiles, to justice issues and how the technologies can influence the labour market, poverty and even legislation. Few of these aspects have been examined in detail before."

Benjamin Sovacool, Aarhus University

The GENIE project

The GENIE ("GeoEngineering and Negative Emission Pathways in Europe") project is set to close this research gap. Its vision is to provide an urgently needed, balanced, rigorous, and interdisciplinary understanding of GGR and geoengineering technologies.

The ultimate goal is to provide a critical assessment of technically feasible, politically acceptable and socially legitimate CO_2 removal and climate engineering pathways that can be deployed in time and at scale.

Even though less frequently discussed and some being very controversial, it is a

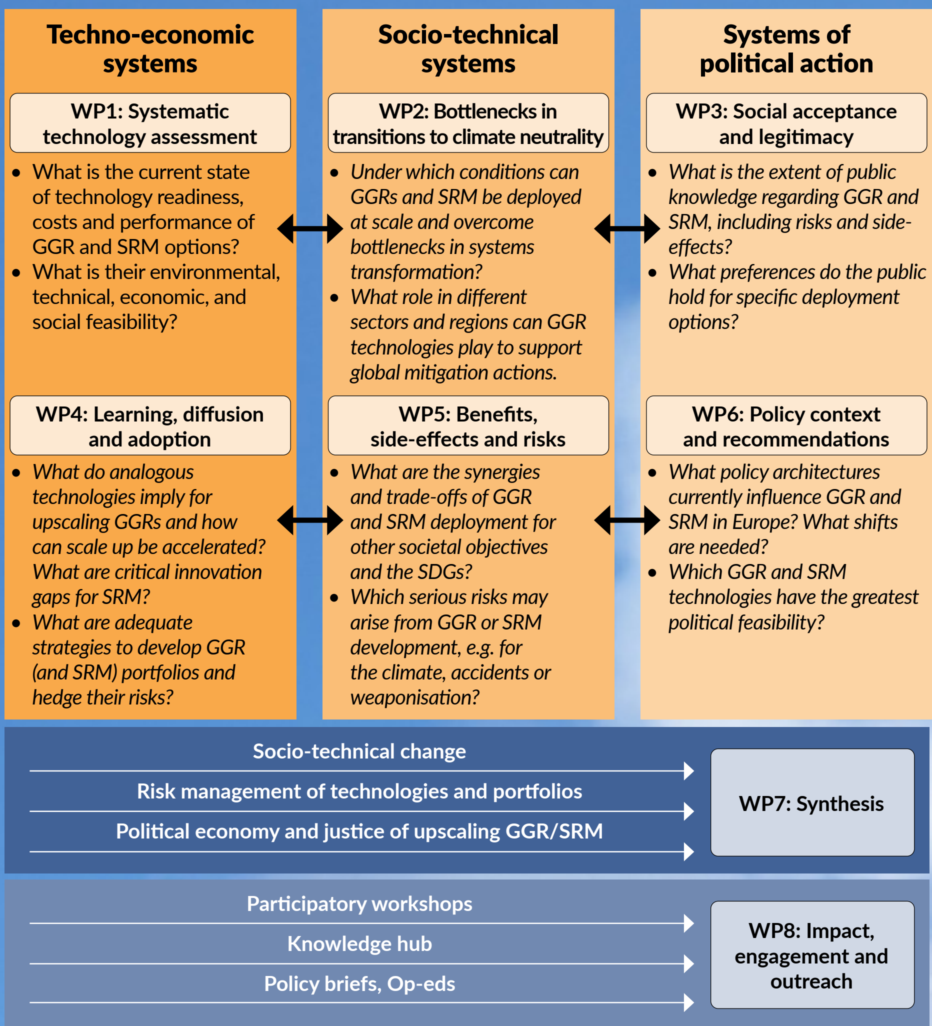

Figure 2: Summary of the GENIE project's eight work packages and cross-cutting themes.

Activity	Impact space	Measures
Extend conceptual understanding of negative emissions and geoengineering typologies.	Academic community has a better conceptual understanding of deployment barriers and processes.	Publication in high impact, open-access, peer-reviewed journals.
Generate new interdisciplinary knowledge on best governing GGR and SRM technologies.	Decision-makers have a better understanding of the cross-cutting impact of different pathways on society. They are also better able to value the possible risks of transformation implementation and find ways to manage risks.	During focus groups, stakeholders will be asked to fill in a feedback questionnaire. This impact is considered to be satisfactorily achieved if ~75 per cent of respondents state that they have improved insights on challenges and opportunities around transformation pathways.
Create new insights on how synergies between negative emissions and geoengineering with mitigation and adaptation.	Decision-makers have a better understanding of the capabilities and skills required to pursue different regional green transformation pathways.	Six targeted policy briefs will translate research findings into actionable policy suggestions.

Table 1: GENIE activities, impact spaces, and measures.

basic responsibility of science in the fight against climate change to consider all technologies and systematically explore the full solution space. This needs to include the opportunities and risks of the new technologies, some of which might develop fast over the coming decade. The more we know about them now, the better policymakers can regulate them or accelerate them nationally and globally.

Tackling climate change is a wicked policy problem (Pielke, 2007) that pervades in all areas of society. For this reason, GENIE is deeply interdisciplinary and rooted in a meta-theoretical framework designed to systematically explore the interrelated techno-economic, socio-technical and political-action systems that underpin the potential role of GGR and SRM in the fight against global warming.

Structure and scientific contributions

GENIE will comprise of six substantive work packages (WPs) and two cross-cutting WPs (Figure 1)—all are highly interconnected with interfaces for information exchange. By doing so, GENIE aims to make at least three substantial scientific contributions:

- GENIE will develop comprehensive and consistent social science on CO_2 removal and climate engineering in critical areas. This includes a new, granular theory and model for learning, diffusion and technology adoption and fills the void in research that systematically explores the role of public perception and preferences in shaping political actions.
- GENIE will consolidate and aggregate a rapidly expanding evidence base on CO_2 removal and climate engineering using data science approaches to stay abreast of dynamic developments in research and technology development across the broad spectrum of options. Further, it/we will use big data approaches to comprehensively track the emerging landscape of coalitions and actors supporting different technologies across digital discourses in social media, newspapers or parliaments.

> "A comprehensive assessment of these non-traditional approaches to climate change will allow policymakers to make more-informed decisions affecting whether, when, how, and how much each of these technologies gets used in our efforts to address climate change."
>
> **Professor Gregory Nemet**
> University of Wisconsin Madison

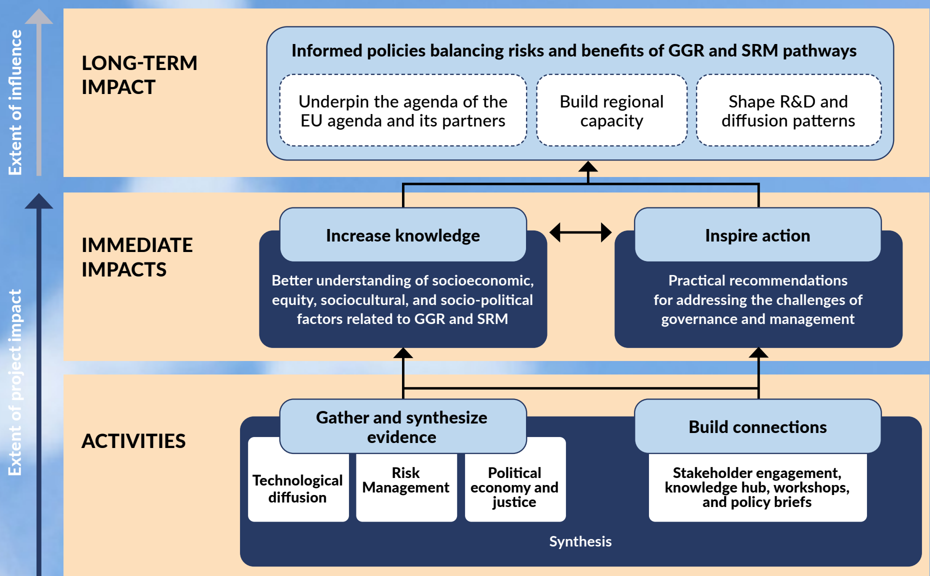

Figure 3: GENIE theory of change.

- GENIE will integrate social science into the systems engineering and economic modelling of transformation processes. A new model generation will feature a comprehensive, up-to-date technology description of the whole set of options, including social processes of technology development and adoption. Specific focus will be given to the social and distributional impacts of the options that may influence public perception and preferences for CO_2 removal or climate engineering options.

Theory of change

The GENIE project is explicitly designed to make a strong contribution to not only climate and energy research but also national policy, European policy, and social impact. Figure 3 shows the impact pathway—or theory of change—for GENIE, setting out how project activities will contribute to achieving expected project impacts. Table 1 provides further detail, such as how the impact of project activities will be measured.

Projected outcomes

- Establish a knowledge hub: a resource for GGR and SRM related information with open access to the GENIE outputs and three main types of tools: *(i)* scenario portals; *(ii)* technology databases; and *(iii)* infographics and interactive maps.
- Contribute to major international scientific assessments: including the IPCC, the Stanford Energy Modelling Forum or the Sustainable Development Goals debate.
- Contribute to national and European policy: by providing a better understanding of the dynamics, interaction and costs of energy and climate policies, by leveraging on the insights emerging from the analysis of different climate pathways, their synergies, and their tradeoffs, as well as the social acceptability of such dimensions.
- Impact ethics and public acceptability of geoengineering and NETs: by informing citizens about the diverse benefits and risks of GGR and SRM, as well as the policy actions that can mitigate their downsides.

The road ahead

GENIE is set to commence in May 2021, with the first results expected to be published in 2023. It is scheduled to run for six years and has been funded by an ERC Synergy Grant.

Co-led by three leading European researchers, further collaborations are anticipated in the future.

> "We are pleased about this great opportunity to advance our successful research on atmospheric carbon removal and to analyse the topic of solar radiation management at the same time, with the necessary scientific distance and impartiality. The political debate on this topic has been picking up speed recently—so it is timely that the EU has now launched a major assessment independent of material interests."

Jan Minx, Mercator Research Institute on Global Commons and Climate Change (MCC).

Click here to view references

GENIE
GeoEngineering and Negative Emissions Pathways in Europe

PROJECT SUMMARY

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.

PROJECT TEAM

World leading researchers will integrate insights from social science, engineering and physical science disciplines to provide a comprehensive view of geoengineering, and how they can help with the transition to climate neutrality in Europe and the world. All partners are also leading authors in the current production of reports from the Intergovernmental Panel on Climate Change (IPCC).

PROJECT PARTNERS

Benjamin Sovacool, Aarhus University and Sussex University

Keywan Riahi, International Institute on Applied Systems Analysis

Jan Minx, Mercator Research Institute on Global Commons and Climate Change (MCC)

Gregory Nemet, University of Wisconsin

CONTACT DETAILS

Professor Benjamin K. Sovacool

BenjaminSo@btech.au.dk

https://pure.au.dk/portal/en/persons/benjamin-sovacoo

https://genie-erc.github.io

@AarhusUni
@MCC_Berlin
@IIASAVienna
@ERC_Research

European Research Council
Established by the European Commission

FUNDING

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme under grant agreement No. 951542.

Fighting climate change requires an assessment of all options

References

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S., Aragão, L. E. O. C., Arneth, A., Arora, V., Bates, N. R., Becker, M., Benoit-Cattin, A., Bittig, H. C., Bopp, L., Bultan, S., Chandra, N., Chevallier, F., Chini, L. P., Evans, W., Florentie, L., Forster, P. M., Gasser, T., Gehlen, M., Gilfillan, D., Gkritzalis, T., Gregor, L., Gruber, N., Harris, I., Hartung, K., Haverd, V., Houghton, R. A., Ilyina, T., Jain, A. K., Joetzjer, E., Kadono, K., Kato, E., Kitidis, V., Korsbakken, J. I., Landschützer, P., Lefèvre, N., Lenton, A., Lienert, S., Liu, Z., Lombardozzi, D., Marland, G., Metzl, N., Munro, D. R., Nabel, J. E. M. S., Nakaoka, S.-I., Niwa, Y., O'Brien, K., Ono, T., Palmer, P. I., Pierrot, D., Poulter, B., Resplandy, L., Robertson, E., Rödenbeck, C., Schwinger, J., Séférian, R., Skjelvan, I., Smith, A. J. P., Sutton, A. J., Tanhua, T., Tans, P. P., Tian, H., Tilbrook, B., van der Werf, G., Vuichard, N., Walker, A. P., Wanninkhof, R., Watson, A. J., Willis, D., Wiltshire, A. J., Yuan, W., Yue, X. and Zaehle, S.: Global Carbon Budget 2020, Earth Syst. Sci. Data, 12(4), 3269–3340, doi:10.5194/essd-12-3269-2020, 2020.

Fuss, S., Jones, C.D., Kraxner, F., Peters, G.P., Smith, P., Tavoni, M., Vuuren, D.P. van, Canadell, J.G., Jackson, R.B., Milne, J., Moreira, J.R., Nakicenovic, N., Sharifi, A. and Yamagata, Y. (2016) 'Research priorities for negative emissions' Environ. Res. Lett. 11, 115007.

Hepburn, C., Adlen, E., Beddington, J., Carter, E.A., Fuss, S., Mac Dowell, N., Minx, J.C., Smith, P. and Williams, C.K. (2019) 'The Technological and Economic Prospects for CO_2 Utilization and Removal', *Nature*, 574(7780), pp.87–97. doi:10.1038/s41586-019-1681-6.

Intergovernmental Panel on Climate Change (2014) *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Irvine, P.J., Kravitz, B., Lawrence, M.G., Gerten, D., Caminade, C., Gosling, S.N., Hendy, E.J. et al. (2017) 'Towards a Comprehensive Climate Impacts Assessment of Solar Geoengineering', *Earth's Future*, 5(1), pp.93–106. doi:10.1002/2016EF000389.

Kravitz, B., Macmartin, D.G., Mills, M.J., Richter, J.H., Tilmes, S., Lamarque, J.F., Tribbia, J.J. and Vitt, F. (2017) 'First simulations of designing stratospheric sulfate aerosol geoengineering to meet multiple simultaneous climate objectives', *Journal of Geophysical Research: Atmospheres*, 112(23), pp. 12,616–12,634. doi:10.1002/2017JD026874.

Kravitz, B., and MacMartin, D.G. (2020) 'Uncertainty and the basis for confidence in solar geoengineering research', *Nature Reviews Earth & Environment*, 1, pp.64–75, doi:10.1038/s43017-019-0004-7.

Kriegler, E., Hall, J.W., Held, H., Dawson, R. and Schellnhuber, H.J. (2009) 'Imprecise probability assessment of tipping points in the climate system', *Proceedings of the National Academy of Sciences*, 106(13), pp.5041–5046. doi:10.1073/pnas.0809117106.

Lenton, T.M., Held, H., Kriegler, E., Hall, J.W, Lucht, W., Rahmstorf, S. and Schellnhuber, H.J. (2008) 'Tipping elements in the Earth's climate system', *Proceedings of the National Academy of Sciences*, 105(6) pp.1786–1793. doi:10.1073/pnas.0705414105

Low, S. and Schäfer, S. (2020) 'Is bio-energy carbon capture and storage (BECCS) feasible? The contested authority of integrated assessment modeling', *Energy Research & Social Science*, 60, 101326. doi:10.1016/j.erss.2019.101326.

Minx, J., Lamb, W. F., Callaghan, M. W., Bornmann, L. and Fuss, S. (2017) 'Fast growing research on negative emissions', *Environmental Research Letters*, 12, 035007.

Minx, J.C., Lamb, W.F., Callaghan, M.W., Fuss, S., Hilaire, J., Creutzig, F., Amann, T., Beringer, T., de Oliveira Garcia, W., Hartmann, J., Khanna, T., Lenzi, D., Luderer, G., Nemet, G.F.,Rogelj, J., Smith, P., Vicente-Vicente, J.L., Wilcox, J. and Dominguez, M. (2018) 'Negative emissions—Part 1: Research landscape and synthesis', *Environmental Research Letters*, 13, 063001. doi:10.1088/1748-9326/aabf9b.

National Academies of Sciences, Engineering, and Medicine (2021) *Reflecting Sunlight: Recommendations for Solar Geoengineering Research and Research Governance.* Washington, DC: The National Academies Press. doi:10.17226/25762.

National Research Council (2015a) *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration.* Washington, DC: The National Academies Press. doi:10.17226/18805.

National Research Council (2015b) *Climate Intervention: Reflecting Sunlight to Cool Earth.* Washington, DC: National Academies Press.

Pielke, R.A. (2007) *The Honest Broker: Making Sense of Science in Policy and Politics.* Cambridge: Cambridge University Press.

Tavoni, M., Bosetti, V., Shayegh, S., Drouet, L., Emmerling, J., Fuss, S., Goeschl, T., Guivarch, C., Lontzek, T.S., Manoussi, V., Moreno-Cruz, J., Muri, H., Quass, M.F. and Rickels, W. (2017) *Challenges and Opportunities for Integrated Modeling of Climate Engineering.* FEEM Working Paper No. 38.2017. doi:10.2139/ssrn.3035166.

Xu, Y., Ramanathan, V. and Victor, D.G. (2018) 'Global warming will happen faster than we think', *Nature*, 564(7734), pp.30–32. doi:10.1038/d41586-018-07586-5.

Paradoxes and Metaphors of Time in Early Universe(s)

Making difference for interdisciplinary research

www.proteus-pmte.eu

Apply for our visiting programme, contribute to our real time forum bringing together natural and human sciences, inspire by publishing your videos in our YouTube Channel

Contact: **Dr Silvia De Bianchi**
proteus.researchteam@gmail.com

PROTEUS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 758145