Leverhulme Centre for Climate Change Mitigation (LC^{3}M)

Full publication listing through to November 2022

2022

49) Oppon, E., Richter, J.S., Koh, L.S.C. & Nabayiga, H. (2022) Macro-level economic and environmental sustainability of negative emission technologies; Case study of crushed silicate production for enhanced weathering. *Ecological Economics*, **Volume 204**, Part A, 2023, 107636. https://doi.org/10.1016/j.ecolecon.2022.107636

48) Vienne, A., Poblador, S., Portillo-Estrada, M., Hartmann, J., Ijiehon, S., Wade, P. & Vicca, S. (2022) Enhanced Weathering Using Basalt Rock Powder: Carbon Sequestration, Co-benefits and Risks in a Mesocosm Study With Solanum tuberosum. *Front. Clim*. 4:869456. https://doi.org/10.3389/fclim.2022.869456

47) Kemp, S.J., Lewis, A.L. & Rushton, J.C. (2022) Detection and quantification of low levels of carbonate mineral species using thermogravimetric-mass spectrometry to validate $_{CO2}$ drawdown via enhanced rock weathering. *Applied Geochemistry*, **146**. https://doi.org/10.1016/j.apgeochem.2022.105465

46) Cox, E., Spence, E. & Pidgeon, N. (2022) Deliberating enhanced weathering: Public frames, iconic ecosystems and the governance of carbon removal at scale. *Public Understanding of Science*. doi:10.1177/09636625221112190

45) Semieniuk, G., Holden, P.B., Mercure, J-F, Salas, P., Pollitt, H., Jobson, K., Vercoulen, P., Chewpreecha, U., Edwards, N.R. & Vinuales, J.E. (2022) Stranded fossil-fuel assets translate to major losses for investors in advanced economies. *Nature Climate Change*, **12**, https://doi.org/10.1038/s41558-022-01356-y.

44) Eufrasio, R.M., Kantzas, E.P., Edwards, N.R., Holden, P.B., Pollitt, H., Mercure, J.F., Koh, S.C.L. & Beerling, D.J. (2022) Environmental and health impacts of atmospheric CO_2 removal by enhanced rock weathering depend on nations' energy mix. *Communications Earth & Environment*, **3**, 106. https://doi.org/10.1038/s43247-022-00436-3

43) Kantzas, E.P., Val Martin, M., Lomas, M.R., Eufrasio, R.M., Renforth, P., Lewis, A.L., Taylor, L.L., Mercure, J.F., Pollitt, H., Vercoulen, P.V., Vakilifard, N., Holden, P.B., Edwards, N.R., Koh, L., Pidgeon, N.F., Banwart, S.A. & Beerling, D.J. (2022) Substantial carbon drawdown potential from enhanced rock weathering in the United Kingdom. *Nature Geoscience*, **15**, 382-389. https://doi.org/10.1038/s41561-022-00925-2

[Commentary on #42: *Nature Geoscience*, **15,** 341, 2022]

Paper #24 reports the first coupled dynamic enhanced rock weathering model findings in which a soil profile weathering model is coupled to a land surface model with nitrogen cycle representation. The modelling advance is akin to moving from equilibrium vegetation models developed in the 1980s to dynamic global vegetation models now embedded in Earth system models. It allows us to account mechanistically for N-fertilizer effects on basal mineral weathering rates. Simulations are uniquely (for ERW modelling analyses) constrained by resource production scenarios. We to show adding rock dust to UK agricultural soils could remove between 6 and 30 million tonnes of carbon dioxide (CO_2) from the atmosphere annually by 2050 -- up to 45 per cent of the atmospheric carbon dioxide removal needed for the UK to reach net zero.

42) Redondo-Bermúdez, M., Jorgensen, A., Cameron, R., & Val Martin , M. (2022) Green infrastructure for air quality plus (GI4AQ+): Defining critical dimensions for implementation in schools and the meaning of 'plus' in a UK context, *Nature-Based Solutions*, **Volume 2**, https://doi.org/10.1016/j.nbsj.2022.100017

41) Fung, K. M., Val Martin, M., & Tai, A.P.K. (2022) Modeling the interinfluence of fertiliser-induced NH_3 emission, nitrogen deposition, and aerosol radiative effects using modified CESM2, *Biogeosciences*, **19**, 1635–1655, https://doi.org/10.5194/bg-19-1635-2022

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40) Mercure, J.-F., Salas, P., Vercoulen, P., Semieniuk, G., Lam, A., Pollitt, H., Holden, P.B., Vakilifard, N. Chewpreecha, U., Edwards, N.R. & Vinuales, J.E. (2021) Reframing incentives for climate policy action. *Nature Energy*, **6,** 1133-1139.

39) James, R., Bullock, L., Larkin, C. & Matter, J. (2021) Geological solutions for carbon dioxide removal. *Geoscientist* (autumn), 16-22.

38) Gomez-Casanoas, N., Blanc-Betes, E., Moore, C.E., Bernachi, C.J., Kantola, I. & DeLucia, E.H. (2021) A review of transformative strategies for climate mitigation by grasslands. *Science of the Total Environment*, **799,** 149466.

37) Vakilifard, N., Kantzas, E.P., Edwards, N.R., Holden, P.B. & Beerling, D.J. (2021) The role of enhanced weathering deployment with agriculture in limiting future warming and protecting coral reefs. *Environmental Research Letters*, **19,** 094005.

36) Lewis, A.L., Sarkar, B., Wade, P., Kemp, S.J., Hodson, M.E., Taylor, L.L.,Yeong, K.L., Davies, K., Nelson, P.N., Bird, M.I., Kantola, I.B., Masters, M.D., DeLucia, E., Leake, J.R., Banwart, S.A. & Beerling, D.J. (2021) Effects of mineralogy, chemistry and physical properties of basalts on carbon capture potential and plant-nutrient element release via enhanced weathering. *Applied Geochemistry*, **132,** 105023.

35) Spence, E., Cox, E. & Pidgeon, N. (2021) Exploring cross-national public support for the use of enhanced weathering as a land-based carbon dioxide removal strategy. *Climatic Change*, **165**, art. 23 https://doi.org/10.1007/s10584-021-03050-y.

34) Horton, P., Long, S.P., Smith, P., Banwart, S.A. & Beerling, D.J. (2021) Technologies to deliver food and climate security through agriculture. *Nature Plants*, **7**, 250–255.

33) Epihov, D.Z., Saltonstall, K., Batterman, S.A., Hedin, L.O., Hall, J.S., van Breugel, M., Leake, J.R. & Beerling, D.J. (2021) Legume-microbiome interactions unlock mineral nutrients in regrowing tropical forests. *Proceedings of the National Academy of Sciences, USA*, **118,** e2022241118. https://doi.org/10.1073/pnas.2022241118.

Paper #33 reports enhanced weathering by N_2-fixing legumes trees in tropical forests facilitated by the recruitment of a below-ground microbiome that also benefits neighbouring trees.

32) Cox, E., Spence, E. & Pidgeon, N. (2021) But They told us it was safe! Carbon dioxide removal, fracking, and ripple effects in risk perceptions. *Risk Analysis*. https://doi.org/10.1111/risa.13717.

31) Cox E., Spence, E. & Pidgeon, N. (2021) What people think about Carbon Dioxide Removal. Leverhulme Centre for Climate Change Mitigation, University of Sheffield, U.K. [White Paper] Available at http://lc3m.org/publications/

30) Cox, E., Boettcher, M., Spence, E. & Bellamy, R. (2021) Casting a wider net on ocean NETs. *Frontiers in Climate*. https://doi.org/10.3389/fclim.2021.576294.

29) Taylor, L.L., Driscoll, C.T., Groffman, P.M., Rau, G.H., Blum, J.D. & Beerling, D.J. (2021) Increased carbon capture by a silicate-treated forested watershed affected by acid deposition. *Biogeosciences*, **18**, 169–188.

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28) Blanc-Betes, E., Kantola, I.B., Gomez-Casanovas, N., Hartman, M.D., Parton, W.J., Lewis, A.L., Beerling, D.J. & DeLucia, E.H. (2020) In silico assessment of the potential of basalt amendments to reduce N_2O emissions from bioenergy crops. *GCB Bioenergy*, **13**, 224-241.

Paper #28 reports first evidence from LC^{3}M field trials for consistent mitigation of N_2O fluxes from US corn-belt soils over three growing seasons following basalt amendment.

27) Beerling, D.J., Kantzas, E., Lomas, M.R., Wade, P., Eufrasio, R.M., Renforth, P., Quirk, J., Sarkar, B., Andrews, G., James, R.H., Pearce, C.R., Khanna, M., Koh, L., Quegan, S., Pidgeon, N.F., Janssens, I., Hansen, J. & Banwart, S.A. (2020) Potential for large-scale CO_2 removal via enhanced rock weathering with croplands. *Nature*, **583**, 242-248.

[Commentary on #26: News & Views, *Nature*, **583,** 204-205; Editorial, *Nature*, **583,** 167-168, 2020]

Paper #24 develops the theory to simulate the weathering of particle size distributions, and an initial nation-by-nation assessment of CO_2 removal potential by enhanced weathering constrained by current and future energy policy scenarios using an advanced and robust computationally efficient modelling approach.

26) Cox, E., Spence, E. & Pidgeon, N. (2020) Public perceptions of carbon dioxide removal in the United States and the United Kingdom. *Nature Climate Change*, **10**, 744-749.

25) MacDougall, A.H., Frölicher, T.L., Jones, C.D., Rogelj, J., Matthews, H.D., Zickfeld, K., Arora, V.K., Barrett, N.J., Brovkin, V., Burger, F.A., Eby, M., Eliseev, A.V., Hajima, T., Holden, P.B., Jeltsch-

Thömmes, A., Koven, C., Mengis, N., Menviel, L., Michou, M., Mokhov, I.I., Oka, A., Schwinger, J., Séférian, R., Shaffer, G., Sokolov, A., Tachiiri, K., Tjiputra, J., Wiltshire, A. & Ziehn, T. (2020) Is there warming in the pipeline? A multi-model analysis of the Zero Emissions Commitment from CO_2. *Biogeosciences*, **17**, 2987–3016.

24) Kelland, M.E., Wade, P.W., Lewis, A.L., Taylor, L.L., Sarkar, B., Andrews, M.G., Lomas, M.R., Cotton, T.E.A., Kemp, S.J., James, R.H., Pearce, C.R., Hartley, S.E., Hodson, M.E., Leake, J.R., Banwart, S.A. & Beerling, D.J. (2020) Increased yield and CO_2 sequestration potential with the C_4 cereal *Sorghum bicolor* cultivated in basaltic rock dust-amended agricultural soil. *Global Change Biology*, **26**, 3658–3676.

Paper #24 reports the first evidence from mesocosm experiments that amendment of a UK agricultural soil with crushed basalt increased yields of the C_4 crop Sorhum and introduced a detailed 1-D soil profile PhreeqC reactive transport model for simulating rock grain weathering and carbon capture.

23) Pidgeon, N. (2021) Engaging publics about environmental and technology risks: frames, values and deliberation. *Journal of Risk Research*, **24**, 28-46.

22) Cox, E., Spence, E. & Pidgeon, N. (2020) Incumbency, trust, and the Monsanto effect: stakeholder discourses on greenhouse gas removal. *Environmental Values*, **29**, 197-220.

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21) Cox, E., Royston, S. & Selby, J. (2019) From exports to exercise: how non-energy policies affect energy systems. *Energy Research and Social Science*, **55**, 179-188.

20) Beerling, D.J. (2019) Can plants help us avoid seeding a human-made climate catastrophe? *Plants, People, Planet.* **1,** 310-314.

19) Andrews, M.G. & Taylor, L.L. (2019) Combating climate change through enhanced weathering of agricultural soils. *Elements,* **15**, 253-258.

18) Cox, E. & Edwards, N.R. (2019) Beyond carbon pricing: policy levers for negative emissions technologies. *Climate Policy*, **19**, 1144-1156.

17) Smith, P., Adams, J., Beerling, D.J., Beringer, T., Calvin, K.V., Fuss, S., Griscom, B., Hagemann, N., Kammann, C., Kraxner, F., Minx, J.C., Popp, A., Renforth, P., Vicente-Vicente, J.L. & Keesstra, S. (2019) Land-management options for greenhouse gas removal and their impacts on ecosystem services and the sustainable development goals. *Annual Review of Environment and Resources,* **44,** 255-286.

16) Lawrence, D. M. et al (including Val Martin, M). (2019) The Community Land Model version 5: Description of new features, benchmarking, and impact of forcing uncertainty. *Journal of Advances in Modeling Earth Systems*, **11,** 4245-4287.

2018

15) Arnold, S.R., Lombardozzi, D., J-F Lamarque, T. Richardson, L.K. Emmons, S. Tilmes, S.A. Sitch, G. Folberth, M.J. Hollaway, M. Val Martin (2018) Simulated global climate response to tropospheric ozone-induced changes in plant transpiration, *Geophysical Research Letters*, **45.** https://doi.org/10.1029/2018GL079938

14) Eufrasio-Espinosa, R.M. & Koh, L.S.C. (2019) The UK Path and the Role of NETs to Achieve Decarbonisation. In: Shurpali N., Agarwal A., Srivastava V. (eds) Greenhouse Gas Emissions. Energy, Environment, and Sustainability. *Springer, Singapore*. pp. 87-109.

13) Spence, E., Pidgeon, N. & Pearson, P. (2018) UK public perceptions of Ocean Acidification – The importance of place and environmental identity. *Marine Policy*, **97**, 287-293.

12) Cox, E., Pidgeon, N., Spence, E. & Thomas, G. (2018) Blurred lines: the ethics and policy of greenhouse gas removal at scale. *Frontiers in Environmental Science*, **6,** 1-7.

11) Beerling, D.J., Leake, J.R., Long, S.P., Scholes, J.D., Ton, J., Nelson, P.N., Bird, M.I., Kantzas, E., Taylor, L.L., Sarkar, B., Kelland, M., DeLucia, E., Kantola, I., Müller, C., Rau, G. & Hansen, J. (2018) Farming with crops and rocks to address global climate, food and soil security. *Nature Plants*, **4**, 138-147.

[Commentary on #11: Editorial *Nature* **554**, 404-405, 2018]

Paper #11 reported the first detailed evidenced-based synthesis advancing our understanding of how enhanced rock weathering could operate with agricultural systems to sequester carbon and promote food and soil security

10) Singh, M., Sarkar, B., Sarkar, S., Churchman, J., Bolan, N., Mandal, S., Menon, M., Purakayastha, J. & Beerling, D.J. (2018) Stabilization of soil carbon as influenced by clay mineralogy. *Advances in Agronomy*, **148,** 33-52.

9) Mercure, J.-F., Pollitt, H., Viñuales, J.E., Edwards, N.R., Holden, P.B., Chewpreecha, U., Salas, P., Sognnaes, I., Lam, A. & Knobloch, F. (2018) Macroeconomic impact of stranded fossil fuel assets. *Nature Climate Change*, **8,** 588-593.

8) Shaw, C., Hurth, V., Capstick, S. & Cox, E. (2018) Intermediaries' perspectives on the public's role in the energy transitions needed to deliver UK climate change policy goals. *Energy Policy*, **116,** 267-276

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7) Hansen, J., Sato, M., Kharecha, P., von Schuckmann, K., Beerling, D.J., Cao, J., Marcott, S., Masson-Delmotte, V., Prather, M.J., Rohling, E.J., Shakun, J., Smith, P., Lacis, A., Russell, G. & Ruedy, R. (2017) Young people's burden: requirement of negative CO_2 emissions. *Earth System Dynamics*, **8**, 577-616.

6) Beerling, D.J. (2017) Enhanced rock weathering: biological climate change mitigation with co-benefits for food security? *Biology Letters*, 13, 20170149.

5) Kantola, I.B., Masters, M.D., Beerling, D.J., Long, S.P. & DeLucia, D.H. (2017) Potential of global croplands and bioenergy crops for climate change mitigation through deployment for enhanced weathering. *Biology Letters*, **13,** 20160714.

4) Edwards, D.P., Lim, F., James, R.H., Pearce, C.R., Scholes, J., Freckleton, R.P. & Beerling, D.J. (2017) Climate change mitigation: potential benefits and pitfalls of enhanced rock weathering in tropical agriculture. *Biology Letters*, **13,** 20160715.

3) Lawford-Smith, H. & Currie, A. (2017) Accelerating the carbon cycle: the ethics of enhanced weathering. *Biology Letters*, **13,** 20160859.

2) Taylor, L.L., Beerling, D.J., Quegan, S. & Banwart, S.A. (2017) Simulating carbon capture by enhanced weathering in croplands: an overview of key processes highlighting areas of future model development. *Biology Letters*, **13,** 20160868.

1) Pidgeon, N.F. & Spence, E. (2017) Perceptions of enhanced weathering as a biological negative emissions option. *Biology Letters*, **13,** 20170024.