Expert explainer

Dr Emily Clough

Visiting Senior Researcher (Climate & AI)

Net zero or net hero? The role of AI in the climate crisis

Ada Lovelace Institute

September 2023

Executive summary

This explainer seeks to provide information about the intersection of artificial intelligence (AI) and climate, including the impacts of AI on climate change and how AI is purportedly being used to address climate change.

With the surging increase in investment in AI-for-climate startups, this explainer is primarily intended to be useful to private and public funders of these companies, government agencies interested in climate and AI, and climate and environmental non-governmental organisations who need to get up to speed on the topic. In particular it explores the two strategies of climate adaptation and climate mitigation, and their potential to effect change.

This report concludes with a proposal for a research project that the Ada Lovelace Institute will undertake. The project will explore how funders of AI-for-climate technologies can better consider climate justice issues.[1]

1 Staff CB, 'In-Depth Q&A: What Is "Climate Justice"?' (Carbon Brief, 4 October 2021 https://www.carbonbrief.org/in-depth-qa-what-is-climate-justice/ accessed 29 August 2023

Introduction: climate change and AI

Climate change is one of the most serious societal problems of our time. Global warming reduces the capacity of the Earth to sustain life. Our planet has currently warmed to 1.1C above 1990 levels and is projected to warm to 2.8C by the end of the century, even with the successful implementation of current climate policies.[2]

We are already beginning to see the impact of a warming climate in the wildfires that have ravaged North America and Australia, devastating floods in Pakistan and severe drought in the north-eastern region of the African continent including the countries Sudan, Eritrea, Ethiopia, Djibouti and Somalia. These impacts will worsen as the average temperature increases. The worst effects are predicted to be felt inequitably by lower-income countries and communities, who contribute less greenhouse gas emissions.[3]

The rise in global temperatures has occurred alongside a remarkable growth in the adoption of artificial intelligence (AI)-powered technologies by global governments and international businesses. These phenomena have intersected with each other in several ways, and raise two critical questions – **what role can (or should) AI play in addressing climate change,** and **what considerations must be taken into account by those seeking to do so?**

On one side of the equation are the climate costs of AI. Research has revealed that training and running AI models can require both a significant amount of energy and the use of carbon-intensive hardware, which in turn generates a significant amount of greenhouse gas pollution.[4]

2 'The Emissions Gap Report 2022 - UNEP' (2022) https://www.unep.org/interactive/emissions-gap-report/2022/ Visual feature: The Emissions Gap Report 2022 - UNEP accessed 21 June 2023.

3 'Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty' (Intergovernmental Panel on Climate Change 2018) https://www.ipcc.ch/sr15/ accessed 19 June 2023.

4 Emma Strubell, Ananya Ganesh and Andrew McCallum, 'Energy and Policy Considerations for Deep Learning in NLP' (arXiv, 5 June 2019) http://arxiv.org/abs/1906.02243 accessed 19 November 2022.

Training and running AI models, such as large language models, is a compute-intensive task often requiring the use of energy-intensive specialised computer hardware (for example graphical processing units, or GPUs) and large data centres to store and process data. These data centres require significant electricity to run the models and cool the hardware.[5]

While the lack of publicly available usage data makes precise calculations difficult, data centres are estimated to generate approximately 1% of greenhouse gas emissions.[6]

On the other side of the equation, some researchers and private developers believe AI can be used to develop solutions to the climate crisis. An increasing number of researchers and private firms are creating AI-powered products and services to address climate change, referred to throughout this report as 'AI-for-climate' technologies. AI-for-climate refers to data-intensive technologies and products that use AI or machine learning techniques to address climate change. See 'What is AI-for-climate?'

AI-for-climate technologies include products that monitor weather systems to allow for better warnings about possible storms and flooding,[7] precision agriculture technologies that allow farmers to reduce agricultural inputs,[8] and efficiency-seeking technologies that reduce energy use in buildings or data centres.

5 Alexandra Sasha Luccioni, Sylvain Viguier and Anne-Laure Ligozat, 'Estimating the Carbon Footprint of BLOOM, a 176B Parameter Language Model' (arXiv, 3 November 2022) http://arxiv.org/abs/2211.02001 accessed 23 July 2023.

6 Charlotte Freitag and others, 'The Real Climate and Transformative Impact of ICT: A Critique of Estimates, Trends, and Regulations' (2021) 2 Patterns https://www.cell.com/patterns/abstract/S2666-3899(21)00188-4 accessed 20 November 2022.

7 'AI for the Global Goals | Google - Flood Forecasting' (*AI for the Global Goals | Google - Flood Forecasting*) https://impactchallenge.withgoogle.com/globalgoals/projects/flood-forecasting accessed 12 July 2023.

8 Will Knight, 'John Deere's Self-Driving Tractor Stirs Debate on AI in Farming' *Wired* https://www.wired.com/story/john-deere-self-driving-tractor-stirs-debate-ai-farming/ accessed 12 July 2023.

In 2022, global venture capital funding for climate tech reached $70.1 billion, almost double the figure in 2021.[9] While it is unclear what percentage of this applies to AI technologies specifically, in the UK AI technologies are clearly attracting energy and interest in the sector: the Department for Business, Energy and Industrial Strategy (BEIS) launched a £1.5 million AI for decarbonisation programme,[10] the Alan Turing Institute and BEIS hosted a showcase event of AI for decarbonisation projects,[11] the EU identified AI as being important for implementing the Green Deal,[12] and the UN Environmental Program has highlighted a number of projects using AI to achieve climate goals.[13] BEIS has recently split to form three new departments: the Department for Energy Security and Net Zero, the Department for Science, Innovation and Technology, and the Department for Business and Trade.[14]

Proponents of AI-for-climate technologies argue they present an important opportunity to leverage the power of advanced data analytics to help businesses and governments reach critical international targets for greenhouse gas emissions. These targets set internationally agreed reductions in emissions, designed to limit global warming to well below 2C above pre-industrial levels.[15] However, who stands to benefit from these applications, and will they be effective?

There are relevant parallels with evidence that the use of AI to address other social problems, such as criminal justice[16] and healthcare,[17] has sometimes resulted in ineffective solutions that worsen societal inequalities.

9 'Defying Gravity, 2022 Climate Tech VC Funding Totals $70.1B, up 89% on 2021.' (3 January 2023) https://www.holoniq.com/notes/2022-climate-tech-vc-funding-totals-70-1b-up-89-from-37-0b-in-2021 accessed 17 July 2023.

10 'Apply for the Artificial Intelligence for Decarbonisation Innovation Programme' (GOV.UK) https://www.gov.uk/government/publications/artificial-intelligence-for-decarbonisation-innovation-programme accessed 6 December 2022.

11 'AI for Decarbonisation' https://www.turing.ac.uk/events/ai-decarbonisation accessed 6 December 2022.

12 European Parliament and others, 'The Role of Artificial Intelligence in the European Green Deal' (European Parliament 2021).

13 https://www.facebook.com/unep, 'How Artificial Intelligence Is Helping Tackle Environmental Challenges' (UNEP, 11 July 2022) http://www.unep.org/news-and-stories/story/how-artificial-intelligence-helping-tackle-environmental-challenges accessed 17 July 2023.

14 'Department for Business, Energy & Industrial Strategy' (GOV.UK, 1 August 2023) https://www.gov.uk/government/organisations/department-for-business-energy-and-industrial-strategy accessed 30 August 2023.

15 'The Paris Agreement | UNFCCC' https://unfccc.int/process-and-meetings/the-paris-agreement accessed 21 August 2023.

16 Vincent Sutherland, 'With AI and Criminal Justice, the Devil Is in the Data' (*American Civil Liberties Union*, 2018) https://www.aclu.org/issues/privacy-technology/surveillance-technologies/ai-and-criminal-justice-devil-data accessed 22 June 2023.

17 Heidi Ledford, 'Millions of Black People Affected by Racial Bias in Health-Care Algorithms' (2019) 574 Nature 608.

As governments and private firms integrate AI technologies into a wide range of domains, and as interest in AI-for-climate technologies surges among private and public funders, it is vital to critically assess the impacts and efficacy of these technologies, and whether their benefits are shared among all members of society.

This explainer draws from a literature review of work at the intersection of climate and AI, to outline the ways AI technologies can affect climate change. It puts this work in the context of understanding the unequal impacts of climate change. It concludes by introducing a longer project at the Ada Lovelace Institute that will explore how AI-for-climate founders and funders currently think about the climate impacts of their work and develop a framework to support them to do this more comprehensively.

Brief review of the climate crisis

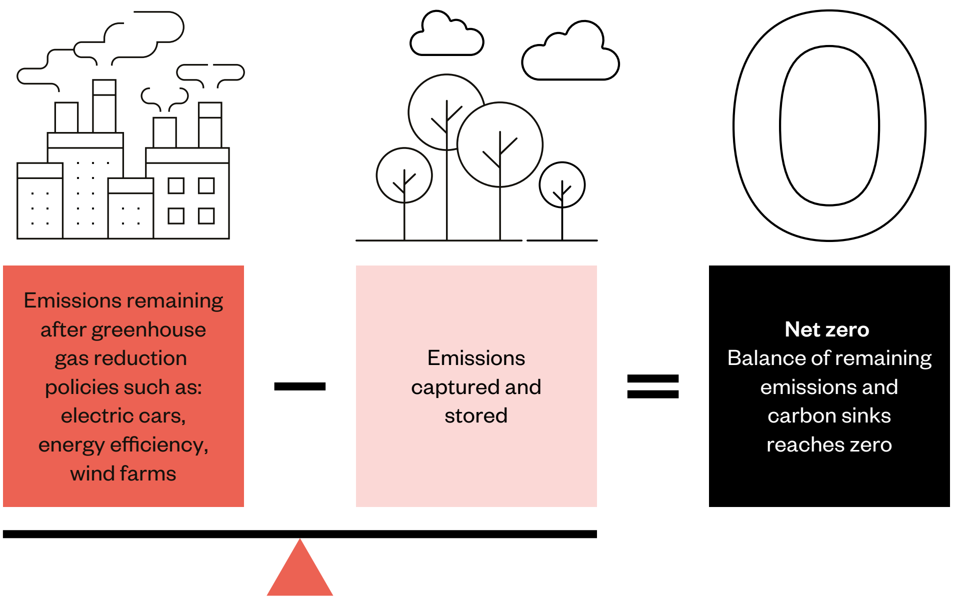
To understand the relationship between AI and climate change, it is important to understand what kinds of human activities have caused climate change and what types of solutions have been proposed to address it.

Scientists have been aware that human activities were leading to increases in outputs of CO2 (carbon dioxide), and to subsequent warming of the atmosphere, since the late 19th century. Human-caused global warming started to receive more scientific attention in the 1950-60s. Scientists began advocate for policy attention to the issue in the 1980s, leading to the creation of the Intergovernmental Panel on Climate Change (IPCC) by the United Nations in 1988.

Net zero

Most climate targets are aimed at achieving net zero. Net zero means that greenhouse gas emissions are counterbalanced by carbon-removal technologies so that the overall balance of emissions is zero. Carbon-removal technologies can include nature-based solutions, such as preserving existing trees and forests, or technologies to remove carbon from the air or from factory emissions, which can be stored or used. Countries' current net zero strategies specify reducing emissions significantly by 2050, but even in the most ambitious climate targets they accept that there will be on average 18% of residual emissions that will require carbon-removal technologies. Residual emissions are emissions that are still present after carbon reduction efforts are complete.

Figure 1: What is net zero?



The IPCC is charged with regular reporting on the scientific consensus across disciplines on the causes and impacts of climate change.[18] In 1992, countries joined in the first international treaty on climate change, the United Nations Framework Convention on Climate Change (UNFCCC), which remains the dominant framework for international negotiations on climate change.

The 2015 Paris Agreement is the latest set of agreements under the UNFCCC. As part of the Paris Agreement, 196 countries committed to work towards the goal of limiting global warming to less than 2C. Subsequent negotiation and study resulted in a clearer target of limiting warming to 1.5C above 1990 levels.[19] To do this, global greenhouse gas emissions must be cut by 45% by 2030, and greenhouse gas emissions would need to decline to 'net zero' (see below) by 2050–60.[20]

Greenhouse gases refer to any of the gases that are responsible for increases in global temperature. The UNFCCC covers emissions of seven of these gases, but the three most commonly discussed are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). greenhouse gas quantities are often expressed in CO2 equivalents, or CO2e.

CO2e expresses the impact of each greenhouse gas in terms of the amount of impact of CO2 it would take to produce the same climate impact. This allows the total climate impact of an activity to be expressed in CO2e, rather than specifying the emissions of each type of greenhouse gas.

Where do greenhouse gases come from? Energy use, such as the burning of fossil fuels for electricity, heat and industrial processes, accounts for 73.2% of total CO2e; of that, 24% of total emissions is from energy use in industry, 16% is from transport and 17% is from energy use in buildings.

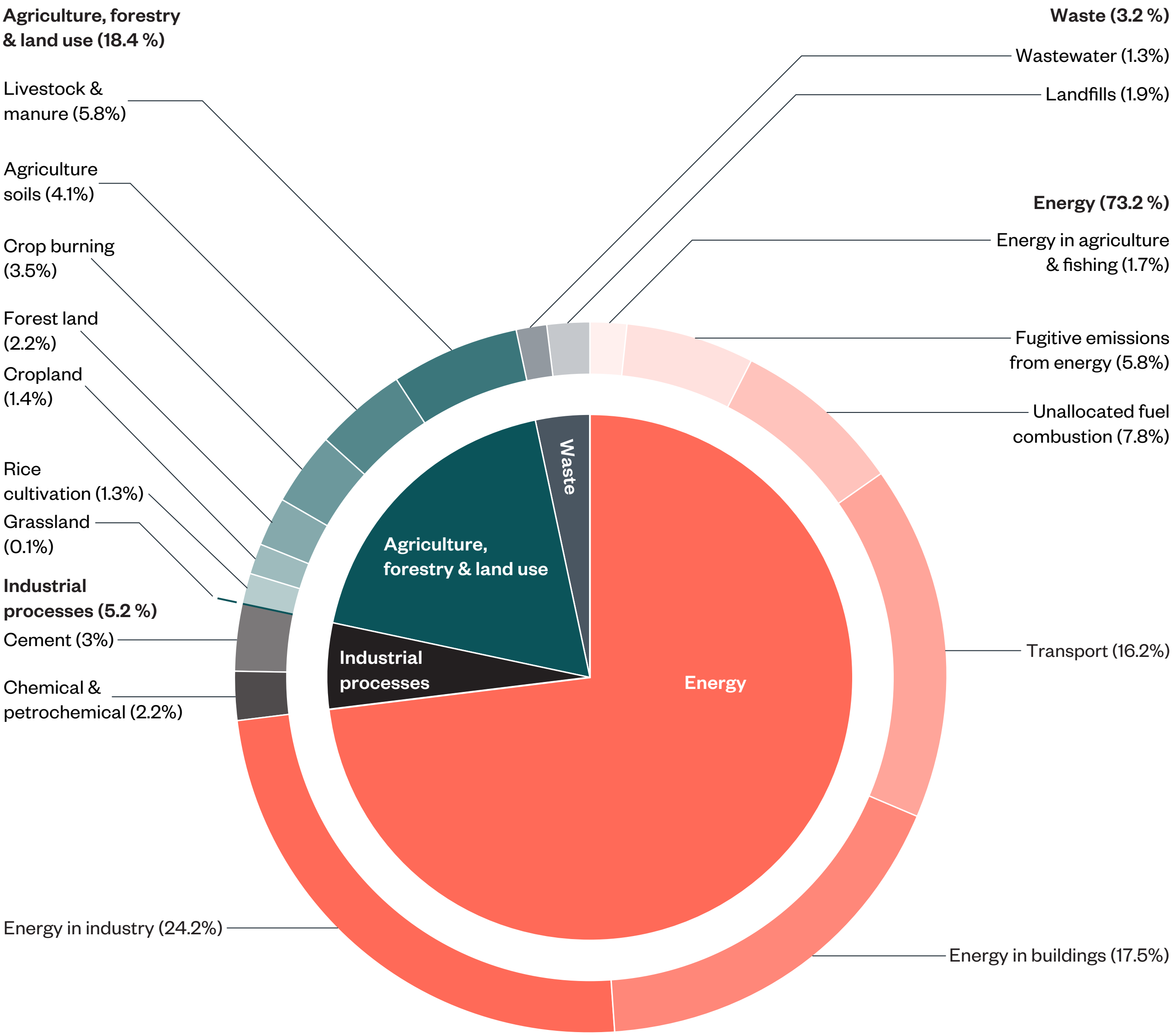
18 'The Origins of the IPCC: How the World Woke up to Climate Change' (*International Science Council*, 10 March 2018) https://council.science/current/blog/the-origins-of-the-ipcc-how-the-world-woke-up-to-climate-change/ accessed 21 August 2023.

19 'Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty' (n 3).

20 'The Evidence Is Clear: The Time for Action Is Now. We Can Halve Emissions by 2030. — IPCC' https://www.ipcc.ch/2022/04/04/ipcc-ar6-wgiii-pressrelease/ accessed 19 June 2023.

Agriculture, forestry and land use accounts for a total of 18% of emissions, not including the energy used in the agricultural industry. Agricultural and land use processes generate CO2 through processes such as crop burning (3.5%), livestock and manure (5.8%) and the degradation of agricultural soils (4.1%). Direct industrial processes, such as the production of cement and chemicals, account for another 5% of emissions, and emissions from waste account for the final 3%.[21]

Figure 2: Greenhouse gas emissions by sector, 2019



21 Hannah Ritchie, Max Roser and Pablo Rosado, 'CO_2 and Greenhouse Gas Emissions' [2020] Our World in Data https://ourworldindata.org/emissions-by-sector accessed 19 June 2023

Climate mitigation and climate adaptation

There are two general categories of plans to address the impacts of climate change: **climate mitigation** plans and **climate adaptation** plans.

Climate mitigation refers to any proposed strategy or plan that will reduce greenhouse gas emissions, and therefore slow or stop global warming. Examples of climate mitigation strategies include the development of renewable energy, reducing livestock farming and consumption, and retrofitting homes for improved efficiency.

Climate adaptation refers to any plan or strategy that will help humans adapt to living on a changing planet with higher greenhouse gas emissions. Examples of climate adaptation strategies include flood controls, improved irrigation systems and providing shade in areas of extreme heat.

Negative impacts of AI on climate

The recent surge in enthusiasm for AI and data-driven technologies has fuelled interest in how they might be applied to address climate change. However, it is important to keep in mind that the development and use of AI technologies can have serious environmental consequences. This section outlines concerns regarding the high energy use and material footprint of AI technologies.

Energy use of data centres and AI

In recent years, the energy use and climate impacts of digital technologies have received increasing attention. Contemporary AI models are often built, trained and deployed on supercomputers using specialised chips. This specialised equipment is housed in large data centres that are mostly operated by cloud computing services such as Google Cloud, Microsoft, Oracle and Amazon Web Services (AWS).

Data centres also provide services, such as data storage and the services we have come to associate with 'the cloud'. Their rapid expansion has resulted in concerns about their use of energy and other local resources such as water and land. Estimates of greenhouse gas emissions outputs of data centres specifically as a proportion of total emissions vary from about 0.6%[22] and 1%.[23]

22 'Data Centres and Data Transmission Networks – Analysis' (IEA) https://www.iea.org/energy-system/buildings/data-centres-and-data-transmission-networks accessed 20 November 2022.
23 Eric Masanet and others, 'Recalibrating Global Data Center Energy-Use Estimates' (2020) 367 Science 984

It is difficult to estimate how much of the overall data centre energy use is a result of AI. Calculating the energy use of an AI model is complicated. It is useful to distinguish between the energy used during training of an AI model, and the energy used during its deployment, or inference stage. AI models are trained once, and this process can take many months. Once the models are trained, they are deployed to be used in applications such as ChatGPT. While energy use from training is significant, it is generally static once the model has been trained.

On the other hand, the energy use from deployment of the models increases as the model use increases. For instance, each query to ChatGPT will use an (unknown) amount of additional electricity, so as use of the product ramps up, so too will the emissions. One attempt to estimate the daily emissions from ChatGPT in February 2023 put those emissions at about 25 tonnes CO2e per day, approximately the same daily emissions as 600 US people.[24]

Most private companies consider information on the compute or data required to train and deploy a model to be proprietary information, which means it is not publicly available, and this makes it even more difficult to estimate the likely emissions. Hugging Face, a machine learning company committed to developing open source models, has made a public estimation of the greenhouse gas emissions of its BLOOM large language model.

Its estimate focuses on three sources of emissions: embodied emissions that went into the creation of the computing hardware, the dynamic consumption required to run the model, and the idle consumption to maintain the infrastructure even when it is not in use.[25] For the training phase of their model, it found that about half the emissions were attributable to dynamic consumption, with the remainder split relatively evenly between embodied emissions and idle consumption.

24 Chris Pointon, 'The Carbon Footprint of ChatGPT' (*Medium*, 19 April 2023) https://medium.com/@chrispointon/the-carbon-footprint-of-chatgpt-e1bc14e4cc2a accessed 1 August 2023.
25 Luccioni, Viguier and Ligozat (n 5).

Hugging Face's results are interesting but cannot be generalised, as the emissions resulting from these three elements depend on the hardware use and the energy make-up of the grid. Overall, training the model produced approximately 50 tonnes of CO2e greenhouse gas. This is the equivalent of nine people making a round-trip flight from London to San Francisco.[26]

Scholars examining the emissions of GPT-3, the model behind ChatGPT, estimated its emissions at 550 tonnes of CO2e, but they acknowledge that, without the data from ChatGPT creator OpenAI, it is impossible to know the exact amount of emissions generated by the model.[27]

Given the rapid escalation of use of AI models, concerns have started to emerge about an increase in AI-generated emissions. The AI industry is already dealing with a shortage of available hardware appropriate to running AI models, and chip manufacturers and cloud service providers are trying to expand to meet demand.[28] This increase in demand raises concerns even among industry about the energy needs of the development and deployment of AI models.[29]

On the other hand, some researchers, especially those with ties to the industry, have argued that the growth in information and communications technology (ICT) emissions is overestimated,[30] or that it could be significantly reduced if appropriate practices and/or regulations are put in place. They argue that improvements in the efficiency of both models and hardware, as well as increased use of renewable energy by data centres, will decrease environmental impacts of AI models even as the models themselves grow more complex. Whether this turns out to be realistic is open to questions, as discussed below in 'Improved efficiency as a solution'.

26 Jocelyn Timperley, 'Should We Give up Flying for the Sake of the Climate?' https://www.bbc.com/future/article/20200218-climate-change-how-to-cut-your-carbon-emissions-when-flying accessed 24 July 2023.

27 David Patterson and others, 'Carbon Emissions and Large Neural Network Training'.

28 Yiwen Lu, 'An A.I. Supercomputer Whirs to Life, Powered by Giant Computer Chips' *The New York Times* (20 July 2023) https://www.nytimes.com/2023/07/20/technology/an-ai-supercomputer-whirs-to-life-powered-by-giant-computer-chips.html accessed 24 July 2023; 'Big Cloud Server Shortage Could Slow Generative AI's Breakneck Pace' (*Insider Intelligence*) https://www.insiderintelligence.com/content/big-cloud-server-shortage-could-slow-generative-ai-s-breakneck-pace accessed 24 July 2023.

29 Jacob Bourne, 'AI Search's High Costs Could Be a Vicious Cycle as Big Tech Eyes Profitability' (*Insider Intelligence*, 13 February 2023) https://www.insiderintelligence.com/content/ai-search-s-high-costs-could-vicious-cycle-big-tech-eyes-profitability accessed 20 July 2023.

30 Masanet and others (n 22); David Patterson and others, 'The Carbon Footprint of Machine Learning Training Will Plateau, Then Shrink' (2022) 55 Computer 18.

Renewable energy as a solution

Significant data centre providers such as Google and AWS have made verbal commitments to using renewable energy to power data centres.[31] It is important to examine these commitments closely, especially with respect to the additionality of the renewable energy used on these projects.

Companies usually acquire renewable energy through power purchase agreements (PPAs) from energy providers in the local grids. PPAs on the scale that major tech companies operate frequently support the development of new projects, but they can simply include the purchase of existing renewable energy from the grid. Particularly in the current environment of energy shortages caused by the Russian invasion of Ukraine, there is competition over who has access to energy.

There are practical limitations on how much renewable energy can be generated due to shortages of space, materials and investment. Renewable energy projects often require the use of rare minerals that also being sought for uses in computing.[32] Solar and wind farms take at least 10 times the space to produce the same amount of energy as fossil fuel power plants, and they frequently encounter opposition from the communities they are located.[33]

In addition, the timing of the provision of renewable energy can make a significant difference to overall greenhouse gas outputs. For instance, AWS has an ambitious solar project in South Africa,[34] which provides significant power for AWS services while the sun is shining. However, it is likely that at night AWS services continue to run on electricity produced by coal, South Africa's largest source of energy. Google is taking a more ambitious approach: its 2020 commitment to reach 24/7 carbon free energy is an important step towards using carbon-free energy to effectively power data centres.[35]

31 'Energy Transition | Amazon Web Services' (*Amazon Web Services, Inc.*) https://aws.amazon.com/energy/sustainability/ accessed 29 November 2022; 'Accelerating Climate Action at Google and Beyond: A Progress Update' 30.

32 IEA, 'Executive Summary – The Role of Critical Minerals in Clean Energy Transitions – Analysis' (IEA) https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary accessed 24 July 2023.

33 Samantha Gross, 'Renewables, Land Use, and Local Opposition in the United States' (Brookings Institute 2020) https://www.brookings.edu/articles/renewables-land-use-and-local-opposition-in-the-united-states/.

34 'Amazon's First South African Solar Plant Delivers Energy and Opportunity' (*US About Amazon*, 22 February 2022) https://www.aboutamazon.com/news/aws/amazons-first-south-african-solar-plant-delivers-energy-and-opportunity accessed 29 November 2022.

35 '24/7 by 2030: Realizing a Carbon-Free Future' (Google 2020) https://www.gstatic.com/gumdrop/sustainability/247-carbon-free-energy.pdf.

Improved efficiency as a solution

Technology companies have invested in improving efficiency of both the models and hardware used to run AI models. Efficiency gains bring both environmental gains and cost benefits, which make them an especially appealing strategy for cost-conscious businesses. Google engineers have argued that using the correct equipment in data centres will reduce the energy use of machine learning models significantly.[36] They estimate that machine learning-optimised hardware reduced energy consumption at Google by a factor of 5.7 to 13.7.

In addition, they argue that shifting to cloud-based data centres would allow for better optimisation of computing resource, and that the use of this more specialised compute method will increase efficiency, and therefore decrease energy and emissions. They predict that these improvements in hardware will help the overall carbon footprint of machine learning to, as described in their paper, 'plateau then shrink'.[37]

While efficiency improvements are an important part of reducing overall energy use, not all the efficiency will be captured in reduced energy use. Increased efficiency can lead to what's known as Jevon's paradox, or a rebound effect. Jevon's paradox occurs when increased efficiency leads to a decrease in price and therefore an increase in demand.[38]

As efficiency and computing power improves, there is little reason to think that this power will be used to run existing models more efficiently. For example, Nvidia has introduced AI-specific microchips that are designed to run AI models more efficiently. The availability of this new, more specialised hardware has allowed for the recent escalation in the development and deployment ever larger and more compute-intensive AI systems.[39] As these new AI technologies are integrated into search engines and the everyday fabric of computing, energy use from computation could escalate rapidly.[40]

---

36 Patterson and others (n 3).

37 Masanet and others (n 22); David Patterson and others, 'The Carbon Footprint of Machine Learning Training Will Plateau, Then Shrink' (2022) 55 Computer 18.

38 The OECD Forum Network, 'The Jevons Paradox and Rebound Effect: Are We Implementing the Right Energy and Climate Change Policies?' (*The OECD Forum Network*, 22 2022) https://www.oecd-forum.org/posts/the-jevons-paradox-and-rebound-effect-are-we-implementing-the-right-energy-and-climate-change-policies accessed 22 August 2023.

39 Rishi Bommasani and others, 'On the Opportunities and Risks of Foundation Models' (arXiv, 12 July 2022) http://arxiv.org/abs/2108.07258 accessed 25 July 2023.

40 Becky Kamansky and others, 'At the Confluence of Digital Rights and Climate & Environmental Justice' (The Engine Room 2022) https://engn.it/climatejusticedigitalrights; Kate Crawford, *Atlas of AI* (Yale University Press 2022).

Material impacts of AI

The environmental impacts of AI go beyond the greenhouse gases generated by energy use. Creating the compute hardware used in data centres to train and run these models, such as central processing units (CPUs) and GPUs, requires sourcing rare earth materials, such as gallium and germanium, that have significant environmental impacts. Building IT equipment requires rare minerals such as lithium and cobalt that are mined in environmentally destructive ways.[41]

At the other end of the lifecycle, when the hardware is replaced, it is difficult to reuse as data centre owners are not willing to take the risk that the hardware is not properly 'wiped', meaning that it is cleaned of all proprietary software and data.[42] Recycling IT equipment is technically and legally challenging, resulting in a growing e-waste problem: it is estimated that 53.6 million metric tonnes (Mt) of e-waste (electronic waste) was produced in 2019, and this number is predicted to increase to 74 Mt by 2030. Of that 53.6 Mt, only 17.4% was recycled, meaning that the majority went intro traditional waste streams, like incineration or landfill. The UN's E-waste Monitor estimates the value of the discarded metals in this e-waste was $57 billion USD.[43]

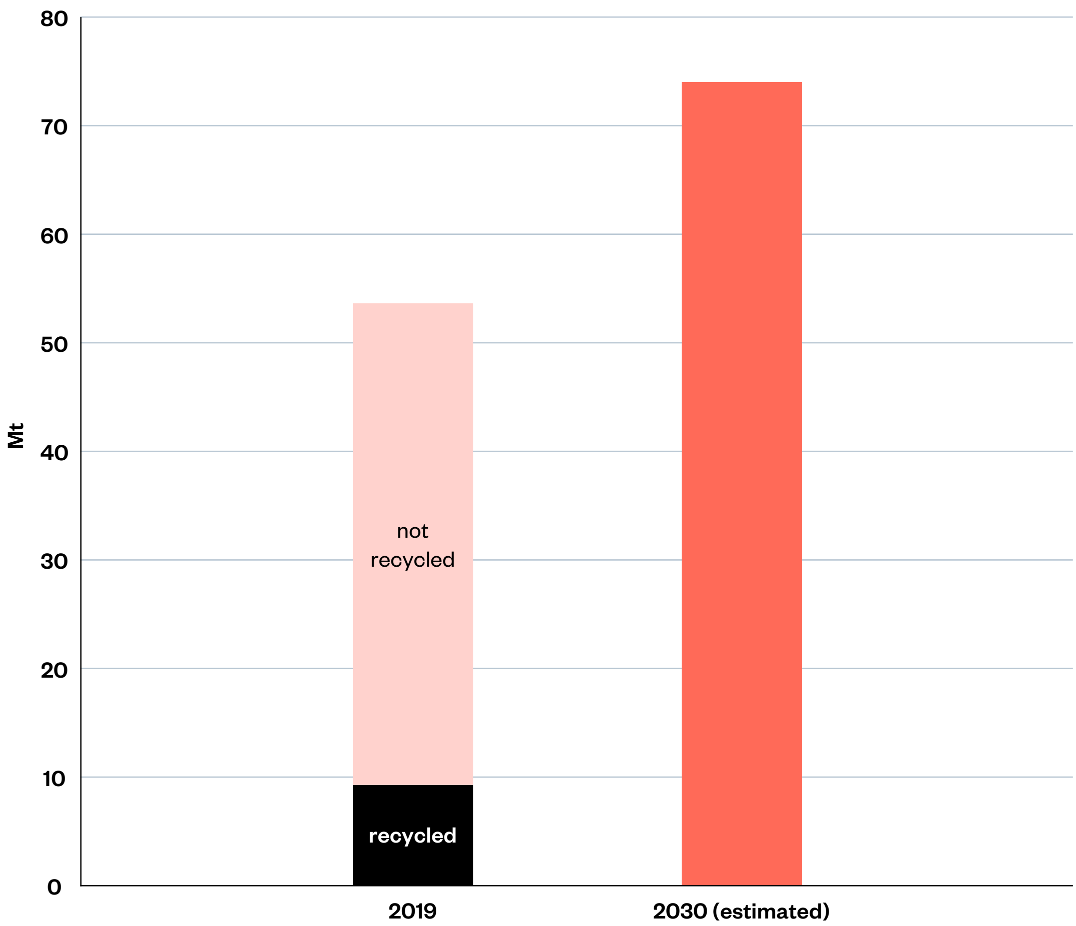
41 Becky Kamansky and others, 'At the Confluence of Digital Rights and Climate & Environmental Justice' (The Engine Room 2022) https://engn.it/climatejusticedigitalrights; Kate Crawford, *Atlas of AI* (Yale University Press 2022).

42 'Why Big Tech Shreds Millions of Storage Devices It Could Reuse | Financial Times' https://www.ft.com/content/31185370-87f3-4ecb-b64d-341bbc4e5c22 accessed 5 December 2022.

43 Vanessa Forti and others, 'The Global E-Waste Monitor 2020: Quantities, Flows and the Circular Economy Potential' (United Nations University/ United Nations Institute for Training and Research; International Telecomunication Union and International Solid Waste Association).

Unrecycled e-waste also can leach toxic metals and substances into ground water, or into the air when burned. Circling back to the discussion on improved efficiencies in 'Improved efficiency as a solution', the e-waste problem raises a serious challenge for proponents of replacing less efficient hardware as a way to address the efficiency problem of AI.

Figure 3: Millions of metric tonnes (Mt) of eWaste



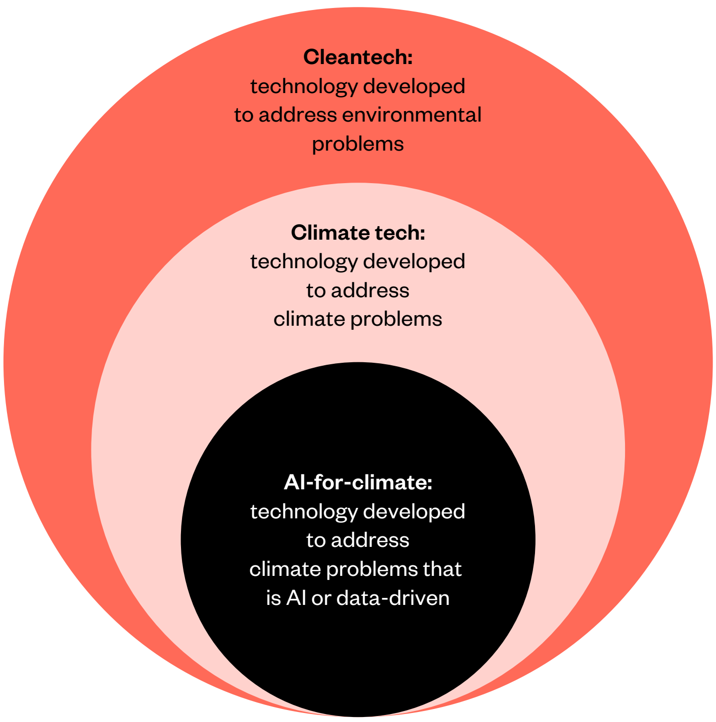
Using AI to address climate change

AI technologies do not just generate climate problems, but also have the potential to ameliorate them – to mitigate or adapt in ways that avoid potential harms. The EU points to the possibility of a 'twin transition' in which digital and environmental transformations in society reinforce one another.[44] This section will outline the world of 'climate tech', meaning the ways that technology has been suggested to address the climate crisis, and the specific contributions that people believe AI can make to that.

Environmental technologies

AI-for-climate technologies are part of the larger ecosystem of technologies developed to address climate and environmental challenges. There are several terms used to refer to these technologies. These terms will be delineated here to explain the place of AI-for-climate in this ecosystem.

Figure 4: Hierarchy of clean tech



44 Steve Muench and others, 'Towards a Green and Digital Future: Key Requirements for Successful Twin Transitions in the European Union' (Publications Office of the European Union 2022) EUR 31075 EN https://publications.jrc.ec.europa.eu/repository/handle/JRC129319.

In the early 2000s, investors and journalists talked about a boom in 'cleantech', understood to be technology that would have a positive environmental impact. This included new types of solar panels, development of biofuels and wind energy. The expression started to fall out of favour in 2016, when an MIT report argued that venture capital companies had lost half of their $25 billion USD investment in this area between 2006 and 2011, and that venture capital funding was a poor match for the needs of cleantech.[45] Cleantech often had high upfront capital costs for physical equipment, with slow returns.

The more recent boom in climate-oriented technologies has instead used the expression 'climate tech', which is understood as technologies that are used specifically to address climate problems, as opposed to the more general environmental orientation of cleantech.

As outlined in the section 'Brief review of the climate crisis', climate problems, climate problems have numerous causes and possible solutions. How do these problems and solutions map on to the climate tech landscape? The influential newsletter Climate Tech Venture Capital (CTVC) identifies seven areas of activity:

1. **Energy**, such as new types of batteries or solar panels.
2. **Food and land use**, such as alternative proteins.
3. **Transportation**, such as low carbon flights.
4. **Built environment**, such as increasing insulation.
5. **Carbon**, such as carbon removal.
6. **Climate management**, such as emissions measurement and tracking.
7. **Industrial** such as new formulations of concrete.[46]

45 Dr Benjamin Gaddy, Dr Varun Sivaram and Dr Francis O'Sullivan, 'The Wrong Model for Clean Energy Innovation'.
46 '$40B and 1,000+ Deals in 2022 Market Downtick' (*Climate Tech* VC, 13 January 2023) https://www.ctvc.co/40b-and-1-000-deals-in-2022-market-downtick/ accessed 3 February 2023.

These seven areas focus almost exclusively on climate mitigation or decarbonisation strategies. Global accounting, audit and assurance corporation PwC uses a broader definition of climate tech, identifying it as technologies that 'directly mitigate or remove emissions, help adapt to climate change, or enhance our understanding of climate change.' [47]

Most climate tech products are classified as hardware, not software, and do not rely on any kind of technique that can be broadly folded under the discipline of artificial intelligence. For instance, a lot of funding and development in recent years has focused on developing new battery technologies or producing alternative forms of protein that generate fewer greenhouse gases than livestock.

It is necessary to differentiate AI-for-climate from the larger climate tech ecosystem, because AI-for-climate solutions are software solutions that specifically use techniques related to the discipline of AI, although they may sometimes involve the development of new hardware to enable the use of those techniques.

What is AI-for-climate?

AI-for-climate refers to data-intensive technologies and products that use AI or machine learning techniques to address climate change.

AI-for-climate technologies are the subject of increasing public and private investment. UK public AI and innovation funding bodies such UK Research and Innovation (UKRI)[48] and the Alan Turing Institute[49] have made significant investments to support the development of AI tools that have the potential to help decarbonise the economy.

47 PricewaterhouseCoopers, 'State of Climate Tech 2021' (*PwC*) https://www.pwc.com/gx/en/services/sustainability/publications/state-of-climate-tech.html accessed 19 May 2023.
48 'Artificial Intelligence Research to Enable UK's Net Zero Target' (25 November 2022) https://www.ukri.org/opportunity/artificial-intelligence-research-to-enable-uks-net-zero-target/ accessed 17 May 2023.
49 'AI Has Critical Role to Play in Helping Tackle the Climate Crisis, New Turing White Paper Finds' (The Alan Turing Institute) https://www.turing.ac.uk/news/ai-has-critical-role-play-helping-tackle-climate-crisis-new-turing-white-paper-finds accessed 17 May 2023.

'AI-for-climate' investment accounts for a substantial part of growth in the overall clean tech or climate tech sector, which has attracted increased investment from private capital in the last few years.[50]

Like climate tech, AI-for-climate technologies are being developed to address the seven areas identified above by CTVC and for the mitigation, adaptation and information solutions identified by PwC. They are, therefore, pervasive throughout the climate tech ecosystem, while remaining in some ways distinct.

A 2021 Global Partnership for AI (GPAI) report identifies four themes for how AI can accelerate climate action:[51]

1. Using AI techniques to 'distil raw data into actionable information', for instance detecting deforestation in satellite imagery.
2. Using AI to make more precise predictions, for instance in operating solar grids or making decisions about farming.
3. Using AI's optimisation capabilities to increase efficiency, and decrease energy use, for instance by optimizing freight transport schedules.
4. Using AI modelling for advancing scientific discovery, such as finding new materials for renewable energy systems or creating new climate models.

These uses could be implemented across any of the seven climate verticals identified by CTVC.

50 Myles McCormick, 'Climate Tech Investment Boom Offers Hope' *Financial Times* (19 March 2022) https://www.ft.com/content/f65cf838-5adf-4720-92f2-e52abae74bc1 accessed 17 May 2023.

51 Peter Clutton-Brock and others, 'Climate Change and AI: Recommendations for Government Action' (Global Partnership on AI 2021) https://www.gpai.ai/projects/climate-change-and-ai.pdf.

The use of AI for climate change mitigation has some potential to contribute to the scale and pace of change needed to achieve net zero by 2050 and the Paris Agreement goal of 1.5C of post-1990 warming, and it will require every tool at our disposal. For example, ClimateTRACE, which is part of the first theme GPAI outlined above, promises some genuine steps forward. It uses satellite data and AI models to track and trace greenhouse gas emissions at an unprecedented level of detail, facilitating better policy making and greater accountability for emissions.[52]

GPAI's themes focus on climate mitigation, but AI is also being used to address climate adaptation. Some of the most widely promoted climate adaptation strategies are based on AI, but there are currently not many voices calling explicitly for AI to be used for this purpose.

Potential uses of AI for climate adaptation include water management strategies that use sensors and AI to redirect water flows to help prevent flooding. For example, the CENTAUR system uses decentralised data collection and algorithms to direct sewer flows, and has been used in cities in the UK, Portugal and France to provide a more decentralised and less expensive way of managing water.[53]

In farming, the increased use of monitoring and modelling tools can help farmers adapt under increasingly climate-stressed circumstances. For instance, precision water management through sensors, weather data and modelling have the potential to help farmers make decisions about where and when to water, as well as how much water to use. As these are still untested technologies, it is difficult to say now what their long-term impacts will be.

52 'Climate TRACE' https://climatetrace.org accessed 6 December 2022.
53 Jonathan Sykes, 'How AI Can Turn "Smart" Sewers into Our First Line of Flood Defences' (*City Monitor*, 21 October 2019) https://citymonitor.ai/smart-cities/how-ai-can-turn-smart-sewers-our-first-line-flood-defences-4618 accessed 22 June 2023.

The role of climate justice

To fully understand the possible impacts of new AI-for-climate products, it is important to understand that climate change will not affect all communities or individuals in the same way. It is well understood that climate change will impact lower-income countries and communities more than higher-income communities and countries.[54]

In other domains like criminal justice and health, so-called 'AI-for-good' technologies can have unintentional negative impacts, sometimes worsening inequalities in areas where they've been deployed.[55] It is important, therefore, to understand the unequal terrain on which AI-for-climate products will be deployed.

The impacts of climate change will not be felt evenly: the worst impacts of extreme heat and drought will be felt by those countries nearest the equator, especially in the tropics.[56] Cities, particularly those with less green space, will also have higher temperatures and more heat waves.[57] This means that residents of lower-income communities and countries are most likely to feel the impacts of climate change. Due to lack of resources, they will also find it more challenging to adapt effectively.

Low and middle-income countries and communities, which industrialised more recently, are also generally those that have produced the fewest cumulative emissions.[58] These differential impacts and responsibilities lead to what is known as the **climate justice problem.**[59]

54 Sivan Kartha and others, 'The Carbon Inequality Era: An Assessment of the Global Distribution of Consumption Emissions among Individuals from 1990 to 2015 and Beyond' (Oxfam, Stockholm Environment Institute 2020) http://hdl.handle.net/10546/621049 accessed 23 August 2023.

55 Ben Green, '"Good" Isn't Good Enough' (2019).

56 'Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty' (n 3).

57 Cynthia Rosenzweig and others (eds), *Second Assessment Report on Climate Change and Cities (ARC3.2) 2018 | Urban Climate Change Research Network* (Cambridge University Press 2018) https://uccrn.ei.columbia.edu/arc3.2 accessed 20 June 2023.

58 'Who Has Contributed Most to Global CO2 Emissions?' (*Our World in Data*) https://ourworldindata.org/contributed-most-global-co2 accessed 20 June 2023.

59 Carbon Brief Staff, 'In-Depth Q&A: What Is "Climate Justice"?' (*Carbon Brief*, 4 October 2021) https://www.carbonbrief.org/in-depth-qa-what-is-climate-justice/ accessed 20 June 2023; Farhana Sultana, 'Critical Climate Justice' (2022) 188 The Geographical Journal 118.

Acknowledgement of the climate justice problem underlies a significant amount of UN decision-making and policy development on climate change. For instance, the agreement to try to limit warming to 1.5C as part of the Paris Agreement was reached after the IPCC produced a report outlining how much worse off lower-income countries would be if warming reached 2C.[60] Corporate commitments to act in accordance with the Paris Agreement should focus not just on the emissions reductions to reach 1.5C, but also on the underlying climate justice reasoning that motivates that goal.

One of the key elements of climate justice is the concept of a just transition, in which the transition to a low-carbon economy does not involve further harm to low-income communities or those with relatively less power. Well-intentioned proposed solutions to climate change can exacerbate inequalities. For instance, using land and resources in low-income countries for carbon-removal projects that are intended to enable further emissions in higher-income countries can be viewed through a lens of resource extraction and colonialism[61]

More than half of the minerals considered to be necessary for a transition to a net zero economy are located in or near the lands of indigenous peoples.[62] For instance, extraction of lithium, a necessary element of car batteries, in the Atacama desert of Chile has led to water overuse, and associated community conflict.[63]

Recycling plastic to create so-called sustainable aviation fuel sounds like a straightforward win-win climate solution. However, the production of this fuel is predicted to have negative impacts on the communities where production plants are located, such as Gary, Indiana, which is a low-income American community that has already been subjected to the negative health impacts of industrial development.[64]

60 'Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty' (n 3).

61 Farhana Sultana, 'The Unbearable Heaviness of Climate Coloniality' (2022) 99 Political Geography https://linkinghub.elsevier.com/retrieve/pii/S096262982200052X accessed 23 August 2023; 'What Can the Digital Rights Community Do to Support Climate Justice Work? Learnings from Our Community Call | The Engine Room' (4 November 2022) https://www.theengineroom.org/what-can-the-digital-rights-community-do-to-support-climate-justice-work-learnings-from-our-community-call/ accessed 2 December 2022.

62 John R Owen and others, 'Energy Transition Minerals and Their Intersection with Land-Connected Peoples' (2023) 6 Nature Sustainability 203.

63 Bárbara Jerez, Ingrid Garcés and Robinson Torres, 'Lithium Extractivism and Water Injustices in the Salar de Atacama, Chile: The Colonial Shadow of Green Electromobility' (2021) 87 Political Geography 102382.

64 Katelyn Weisbrod, 'A Gary, Indiana Plant Would Make Jet Fuel From Trash and Plastic. Residents Are Pushing Back' (*Inside Climate News*, 12 December 2022) https://insideclimatenews.org/news/12122022/gary-indiana-plastic-jet-fuel/ accessed 20 June 2023.

Applying a climate justice lens to new technologies also requires us to consider whose needs are being addressed. For instance, a lot of money and enthusiasm in the transition to carbon-free transport has focused on the electrification of private passenger vehicles such as cars and larger sports utility vehicles (SUVs).

Personal cars are the main form of transport in higher-income countries, whereas lower and middle-income countries tend to rely more on scooters or public transport.[65] A shift in transport technology that focuses only on private passenger vehicles threatens to leave behind lower-income communities and countries.

Climate justice issues could play out differently in the context of climate mitigation applications rather than climate adaptation applications.

When developing climate mitigation technologies, it is important to be especially aware of negative impacts of their development or deployment on communities that have less power.

When developing climate adaptation technologies, it is important to also be particularly attentive to which communities are being helped to adapt to the changes wrought by a warming planet. Will the new technology further the adaptation of those communities that are suffering most from the impacts of climate change, and who often have done least to contribute to global warming?

65 'Climate Tech Insights from Latin America, Ep #13 – Invested in Climate' https://investedinclimate.com/podcast/climate-tech-insights-from-latin-america-ep-13/ accessed 20 June 2023.

The role of funders

Whether startups working on AI-for-climate solutions will consider climate justice issues will depend in large part on the role of public and private funders, who can set incentives and requirements for startups that determine their eligibility to receive an investment.

Climate tech has been regarded as a growth area for venture capital funding over the last few years. Climate tech startups and scaleups accounted for approximately 3% of global tech investment in 2017, and were estimated to account for almost 20% of venture capital in Q1 2023.

It is not clear how much of that funding is for AI-for-climate specifically, but with the general growth of interest in AI and data-driven technologies it is likely that AI-for-climate funding is on the rise as well. For instance, Carbon Re, a UK-based start-up using AI technologies to improve efficiency and thus decrease emissions in cement production, recently raised a seed round of £4.2 million.[66]

Funding for development of AI-for-climate technologies and products can come from public sources, either directly through government departments such as the UK's BEIS (now split to form three new departments)[67] or more indirectly through funding to universities and research organisations through UK Research and Innovation (UKRI)[68] or the Alan Turing Institute.[69]

66 Haje Jan Kamps, 'Carbon Re Spins out of Academia-Land to Take on Cement Pollution' (*Tech Crunch*, 7 November 2022) https://techcrunch.com/2022/11/07/carbon-re-round/ accessed 23 August 2023.
67 Department for Business, Energy & Industrial Strategy (n14).
68 'Artificial Intelligence Research to Enable UK's Net Zero Target' (n 46).
69 'AI for Decarbonisation' (n 11).

Many venture capital funders in the climate tech space are impact-investing firms. Impact investing is defined as 'investments made with the intention to generate positive, measurable social and environmental impact alongside a financial return'.[70] Impact investing is different from investing with environmental, social and governance (ESG) factors in mind. Impact investing requires making positive choices about investments that will have impact, whereas ESG investing is more focused on using ESG criteria as a negative screen.

For instance, an impact investor might be looking for investments that promise a certain level of emission reductions, but wouldn't necessarily consider other issues of how the company is run or its broader societal impact, as captured in its ESG rating. On the other hand, an ESG investor might be interested in investing in a company that produces lots of emissions, but that passes the investors thresholds for ESG criteria.

Impact investors in the climate tech space include:

- general impact venture capital firms that include an environmental component, such as Zinc Ventures, which runs programmes to 'build brand new, commercial, mission-driven companies that tackle the biggest social challenges' in its four missions of mental health, later life, environment and globalisation.[71]

- impact venture capital firms with a specific focus on climate change, such as Marble, which 'partners with scientists, engineers and operators to build deeptech startups that slash emissions, remove carbon from the atmosphere and create climate resilience' [72]

- charitable enterprises that have a venture capital arm doing impact investing in climate, such as UNICEF Ventures, which 'makes $50–100K early stage investments in technologies for children developed by UNICEF country offices or companies in UNICEF programme countries'.[73]

70 J Penney Frohling and others, 'Estimating and Describing the UK Impact Investing Market' (Impact Investing Institute 2022) https://www.impactinvest.org.uk/wp-content/uploads/2023/04/Estimating-and-describing-the-UK-impact-investing-market.pdf accessed 21 June 2023.

71 'Environment - Zinc' (25 August 2021) https://www.zinc.vc/missions/environment/ accessed 21 June 2023.

72 'Marble - About' https://marble.studio/about accessed 21 June 2023.

73 'UNICEF Venture Fund | UNICEF Office of Innovation' https://www.unicef.org/innovation/venturefund accessed 21 June 2023.

Both publicly funded AI-for-climate and impact investing in AI-for-climate require that the climate impact of their work is understood and measured. In impact investing, the idea of measurable social impact is key to what these firms are trying to achieve, and often the limited partners who supply funding to impact venture capital firms require them to demonstrate that they are having the positive social impacts they claim. In publicly funded AI-for-climate work, it is important that the positive impacts of investment are understood.

As discussed above, climate goals are often expressed in terms of greenhouse gas emission reductions. However, impact investing and public funding are both concerned with larger social good. This means that it is particularly important to understand how climate justice factors into their decision-making.

Future work – what's next for Ada on climate and AI?

Over the next 12 months, the Ada Lovelace Institute will explore how climate justice is considered in the development of AI-for-climate products. In addition to understanding the perspectives of companies developing AI-for-climate products, it will examine how funders of climate tech think about climate justice when making funding decisions. It will contribute to the increasing interest in understanding how funding influences the development of AI in general.[74]

This project has two goals:

1. Understanding if and how climate tech founders and funders include climate justice considerations in product development.

2. Developing and promoting a framework and procedure that climate tech founders and funders can use to evaluate climate justice concerns in the development of new climate products.

74 Eticas, 'How Public Money Is Shaping the Future Direction of AI: An Analysis of the EU's Investment in AI Development' (European Artifical Intelligence & Society Fund 2023) https://eticas.tech/wp-content/uploads/2023/03/28032023-EU-Investments-Report_ESAIF-and-Eticas.pdf.

The project will begin with interviews with AI-for-climate funders and founders. It will seek to understand the below points:

- How do funders and founders think about and measure the climate impacts of the AI-for-climate products they develop and fund? What motivates them to focus on certain aspects or measures of climate impact?
- How do they think about the impact of AI-for-climate products on their users? Do they consider the potential inequalities in who will have access to their products? Are their evaluations of impacts of their products informed by an understanding of the climate justice problem?
- If funders and founders do examine issues of climate justice in the development of their products, what approaches have they found to be useful? What would be accelerants or blockers to integrating climate justice impacts more thoroughly into their process?

The project will then create and test a framework for examining climate justice impacts that funders and founders will be able to use to increase the positive climate results they are trying to achieve.

If you are a funder of AI-for-climate technologies, or a founder of a startup working in this space, we would like to talk to you.
Please email hello@adalovelaceinstitute.org for more information.

About the author

Dr Emily Clough is Visiting Senior Researcher (Climate change & AI) at the Ada Lovelace Institute. She is leading a project on the scope and funding of data-driven climate technologies. Her research interests include the ways in which emerging climate technologies interact with climate justice.

Emily has a PhD in Political Science from the University of Minnesota. Before joining the Ada Lovelace Institute, she taught at environmental politics and quantitative methods universities in the USA, UK and France. Emily's most recent role was Senior Lecturer in politics at Newcastle University, where she published peer-reviewed research on climate change, environmental justice and the UN Sustainable Development Goals. She has also worked as a consultant to the UN Department of Economic and Social Affairs on the Sustainable Development Goals.

About the Ada Lovelace Institute

The Ada Lovelace Institute was established by the Nuffield Foundation in early 2018, in collaboration with the Alan Turing Institute, the Royal Society, the British Academy, the Royal Statistical Society, the Wellcome Trust, Luminate, techUK and the Nuffield Council on Bioethics.

The mission of the Ada Lovelace Institute is to ensure that data and AI work for people and society. We believe that a world where data and AI work for people and society is a world in which the opportunities, benefits and privileges generated by data and AI are justly and equitably distributed and experienced.

We recognise the power asymmetries that exist in ethical and legal debates around the development of data-driven technologies, and will represent people in those conversations. We focus not on the types of technologies we want to build, but on the types of societies we want to build.

Through research, policy and practice, we aim to ensure that the transformative power of data and AI is used and harnessed in ways that maximise social wellbeing and put technology at the service of humanity.

We are funded by the Nuffield Foundation, an independent charitable trust with a mission to advance social wellbeing. The Foundation funds research that informs social policy, primarily in education, welfare and justice. It also provides opportunities for young people to develop skills and confidence in STEM and research. In addition to the Ada Lovelace Institute, the Foundation is also the founder and co-funder of the Nuffield Council on Bioethics and the Nuffield Family Justice Observatory.

Find out more:

Website: Adalovelaceinstitute.org
Twitter: @AdaLovelaceInst
Email: hello@adalovelaceinstitute.org

Preferred citation: Emily Clough, *Net zero or net hero? The role of AI in the climate crisis* (Ada Lovelace Institute 2023) https://www.adalovelaceinstitute.org/resource/climate-change-ai/

ISBN: 978-1-7392615-8-0