frontiers | Frontiers in Climate

TYPE Perspective
PUBLISHED 31 May 2024
DOI 10.3389/fclim.2024.1387079

OPEN ACCESS

EDITED BY
Bamidele Victor Ayodele,
University of Technology Petronas, Malaysia

REVIEWED BY
May Ali Alsaffar,
University of Technology, Iraq

*CORRESPONDENCE
Maximus L. L. Beaumont
max@numa.studio

†PRESENT ADDRESS
Maximus L. L. Beaumont,
NUME Pte, Singapore, Singapore

RECEIVED 12 March 2024
ACCEPTED 13 May 2024
PUBLISHED 31 May 2024

CITATION
Beaumont MLL (2024) Overlooked technological and societal trends that will level-up our fight against climate change. *Front. Clim.* 6:1387079. doi: 10.3389/fclim.2024.1387079

Overlooked technological and societal trends that will level-up our fight against climate change

Maximus L. L. Beaumont*†

Skytree, Amsterdam, Netherlands

Our ability to fight COVID-19 demonstrates that where there's a will, there's a way. Yet proactive action will not be the single driving force behind us winning a stable and benign environment for our children. This article focuses on the not so obvious yet impactful trends affecting our ability to stave off the worst of climate change. These trends include carbon taxation, climate litigation, AI, space exploration, Direct Air Capture and an ever younger, more motivated demographic. Some trends will affect our efforts in unknown and unpredictable ways, while others will drive them with ever more force over the years to come. Carbon taxation requires a proactive change in government policy, but that change will place implementation in the hands of the free market. As we face an existential crisis never before seen by humanity, perhaps the largest driving force affecting our ability to ensure a healthy planet will be a more engaged public.

KEYWORDS

direct air capture (DAC), renewable energy, artificial intelligence, youth activism, carbon tax, space exploration, climate change, carbon credit

Introduction

The world's reaction to the COVID-19 pandemic demonstrates that short-term, drastic action by governments and society is plausible. Ironically, the changes required by society to keep Earth below the ideal 1.5°C warming limit set by the IPCC [a limit which has recently been broken (Copernicus, 2024)], would not be felt nearly as much as the massive government lockdowns and travel restrictions imposed on us over the last few years. So what's the problem? Why can we take drastic and effective action against COVID-19 but not climate change?

The difference is imminent danger and timeline. The virus was and is a very real and immediate threat to human health. At the outbreak, any one of us could have been infected within weeks of discovery of the virus within our countries. Though climate change will have an indirect effect on our health through worsening air quality, extreme weather and natural disasters that occur around us, the risks are not necessarily imminent, near-term, or fatal. The occurrence of climate events is sporadic and dispersed around the globe. Though they affect many millions of people, and are affecting us at an ever greater rate, most of us are left largely untouched and disassociated from them.

It's a natural human trait to be self-centered about risk and also to think in the short-term about the future. The reality is that massive, proactive action will likely not be adopted by governments against climate change until its dangerous effects become noticeable by the vast majority of the population on a regular basis. And until there is a measured decline in economic growth associated with it. It may very well be too late at that point, though let us hope not. Indeed, a recent UN report predicts that we are on track to emit 9% *more* CO_2 in

2030 than in 2010, as opposed 45% *less* which is the conservative minimum required by most IPCC scenarios to stay below reasonable warming limits (United Nations, 2023).

Happily, there are certain overlooked trends in our society today, as well as simple political and economic levers, that will naturally level-up our ability to mitigate climate change. Through little effort of our own, these trends could have a major impact on our fight to reverse global warming. This article is an analysis of those trends.

Economic levers

One of the most accessible algorithms we have today to study the effectiveness of different climate change policies was developed at MIT and is called En-ROADS (2024). In the model, a wide variety of climate mitigation measures can be tweaked. The effect of the measures is converted into a predicted warming rate, and ultimately, the average global temperature in 2050. Most use the software to understand what needs to be done today in order keep warming under 1.5°C. Some of the parameters that can be tweaked include the rate of solar, wind, geothermal and nuclear power deployment, reforestation policy, CCS/CCU capability, rate of electrification and energy efficiency in buildings. There are eighteen parameters in all. By far, and by quite a margin, the policy which has the largest effect on average temperatures in 2050, is carbon tax.

The notion of additional tax on economic activity is frowned upon by many political parties in power today. In fact, we see an almost cult-like reverence for 'free-market' economics. Unfortunately, the notion of the "*invisible hand*" and a "*laissez-faire*" approach to capitalism has been taken out of context. The original literature that coined the approach, Adam Smith's *The Wealth of Nations* and John Maynard Keynes' book *The General Theory of Employment, Interest, and Money*, held that certain economic sectors logically should remain within the purview of the government (Pelc, 2022). And that the goal of economic growth is an equitable distribution of wealth *across* the population of a country, with the ultimate purpose of allowing individuals more free time to engage in their hobbies and passions, such as art, philosophy or simply time with family. The authors predicted this could occur by the early 21st century (Keynes, 1932).

The founders of the free-market economic system were unanimous in their opinion that certain economic sectors should remain under government control and that negative externalities of economic activity would need to be contained. Sectors to be retained under governments' purview, for example, would include public transport, energy distribution, education and healthcare. Economic activities with negative externalities might include the consumption of alcohol, cigarettes and sugar, or the unregulated disposable of hazardous waste products. These impose a cost on society through increased pressure on healthcare systems and the destruction of natural resources. One example of large-scale action against a negative externality, is the banning of CFCs in the 1990s to prevent the destruction of our ozone layer. More recently, the UK has announced plans to ban vapes to reduce addiction in children and associated hospitalization of teenagers (Ferguson, 2023).

Many areas of economic activity are regulated for similar reasons, without question or hesitation. Now, as we face an existential crisis not experienced by humanity since the last major ice-age, surely the founders of our free-market economic thinking would not object to our carbon emissions being regulated? Just like CFCs or vapes, the increased risk imposed by carbon emissions on human health and our natural resources is real. In fact, carbon emissions risk the foundation upon which our very economies are built; a benign and largely predictable weather system.

A reasonable response, and one that we are seeing more and more prevalently, is the imposition of a tax on carbon emissions through carbon emission cap and trade systems. This is accompanied by an incentive of 'credits' for those who are able to re-use or sequester carbon emissions. The beauty of economic levers is that active measures by government are avoided. Instead, the paradigm within which our economic system operates is simply altered. The rest is done naturally by the free-market, and the human drive to be profitable. Levying a consistent tax on carbon emissions, or high carbon intensity products, drives carbon efficiency more than any other government policy.

The EU has had such a tax in place since 1995; it is called the EU-ETS system (European Commission, 2024a). Back in 2010, the price of CO_2 above the allotted cap for an emitter (whether an energy company or other carbon-intensive entity such as a cement producer) was €15 per ton. It has now stabilized at €70 per ton – a remarkable increase over a relatively short time (Trading Economics, 2024). The EU-ETS system covers over 60% of the block's emissions and is speculated to be responsible for double digit percentage reduction in the region's carbon emissions over the same period. The EU has since implemented a "carbon border tax", called the CBAM, which levies the same ETS tax on imported fossil fuel-based energy and other carbon-intensive products, thereby putting domestic production on the same playing field and encouraging a green transition more globally (European Commission, 2024b).

Perhaps more importantly, Biden's Inflation Reduction Act has increased the carbon credit price for carbon sequestered which has resulted in massive growth in the carbon removal industry (The Whitehouse, 2023). The 45Q carbon credit system, in place for the last decade, priced carbon captured or stored at $85 per ton. The IRA has now upped that available credit amount to $180 per ton, further reducing the cost of capturing or re-using carbon, making it even more affordable and thus more likely to be rolled out. Alas, there is no harmonized federal cap and trade system in place in the US. Only fourteen states have active carbon markets, with only 5% of national emissions taxed at $60 per ton, 40% well-below that, and the remaining emissions free riding with no tax placed on them at all. There is a long way to go here, and huge potential to drastically cut emissions by implementing sensible, well thought-through carbon tax policy.

There are even ideas to reduce a carbon tax's burden on society, so that it really only affects the relevant market players (high-intensity emitters). These include balancing the revenue generated from the tax with a reduced level of income tax for the individual. Doing so would more than offset any harm done to the consumer through a trickle-down increase in energy or commodity prices. Some of the tax revenue could also be put towards R&D in climate-tech and the subsidizing (and hence the greater affordability) of renewable energy.

A uniform, federal carbon tax will be a hugely effective policy and has massive potential to reduce emissions via free-market mechanisms (Rajabi, 2023). And as taxes on carbon emissions expand globally, including in China, and become more consistent over the course of the next decade, energy production, manufacturing processes,

corporate operations, and products themselves, will become better and healthier for our planet.

Litigation

A few years ago, a group of American children took legal action against the state of Montana for promoting fossil fuel interests and thereby "violating their constitutional rights to a clean and healthful environment" (Chu, 2023). Among other reasons, the case was partly inspired by recent weather in Montana which was becoming too hot to hike in, triggering forest fires that were destroying natural landscapes and reducing the amount of observable wildlife in the region. Suddenly, Sundays out with the family exploring nature had become less tenable and frankly, less interesting. At the same time, Montana state officials continued to handout new licenses for coal plants.

The children, now young adults or more accurately, youth, were represented by legal counsel Julia Olsen of *Our Children's Trust*, an NGO which provides legal representation for youth across the United States (Our Children's Trust, 2024). A few months ago, they won. It's the first time in global history that a government has been held liable for threatening the health of a younger generation through climate negligence. The case itself will prevent more coal plants from being built in Montana, and that's a good thing. But most importantly, it sets precedent for the dozens of other cases around the US and the world being brought against governments for similar reasons. By taking governments to court everywhere, making them more accountable to the public and more genuine about their efforts to fight climate change, more aggressive climate policies will be effectuated. They could even result in a mandate that governments around the world commit to bolder emissions reductions (Amnesty International, 2023).

Policy tends to follow the will of the people. And if the will of the people is holding politicians to account, not through voting preference, but stone cold legal tenure, then it is hard to see how real climate action can be avoided by current governments.

It's not all roses – fossil fuel stakeholders are fighting back. The state on Montana has appealed, with a final ruling expected this summer. Exxon has taken the Dutch activist investor Follow This to court in Holland. And a case made against the US federal government is at risk of being shot down by an executive order under the assumption that it would cause the government 'irreparable harm'. However, many more cases brought to court by individuals, activist organizations, state and federal governments alike are in the process of going to discovery this year. California's Gavin Newsom has even filed a case against plastic producers while some government bodies are now alleging that fossil fuel companies broke racketeering laws by conspiring to sow doubt about climate crisis (Noor, 2024).

Hands down, the most significant litigation win would be if national governments took legal action against oil companies. Whether that happens is under debate, but it would shift the legal tide against emitters, and those who enable emissions, more than anything else.

Artificial intelligence

The advent of effective generative AI, after decades of development, and catalyzed by access to massive amounts of computing power and data, will affect the world in profound ways. Activities that will be affected by AI include art and poetry, manufacturing, financial services, education, engineering and healthcare.

Similarly, AI will affect our efforts against climate change. Secondary effects through the increased rate of technology development it enables will leave their mark. However, AI is already being put to use to;

- analyze climate data, including satellite data, to improve climate models and more accurately predict climate events
- accelerate the development of genetic modifications to help crops grow more effectively under adverse conditions
- analyze agricultural land to optimize crop growth efficiency
- analyze and monitor reforestation activities, improving real-time legers of carbon sequestration
- optimize power distribution across electricity grids, especially those with large shares of renewable energy
- enable more effective knowledge sharing and collaboration within climate change research

The last point is probably the most profound. Using Large Language Models (LLMs), AI will soon be able to analyze all available scientific data on climate change (by processing published papers) and answer simple queries as to the latest findings. Such capability will allow both those who are simply curious, as well as scientists, to stay up to date with progress and understand which research bodies to contact should they wish to explore certain topics further.

The idea of bringing together research parties should not be underestimated. As we know, the key to most progress in science is the open and effective sharing of ideas. Potential collaborations between research teams have often gone ignored out of simple ignorance of each other. AI's ability to flag previously hard to identify research partners to anyone interested, will accelerate scientific understanding. AI even has the potential to predict where the next breakthroughs will be and who will make them (Evans and Sourati, 2023).

It should be noted that the potential of AI to positively affect our efforts against climate change are ultimately limited by the degree of those efforts themselves. Our fight against climate change depends more on political will, which in turn, depends on popular sentiment. AI will simply make any existing efforts more effective and efficient.

A younger and more motivated demographic

I was born in the mid-eighties and raised internationally, including the Middle-East, Austria and the UK. I'm a millennial through and through. As a result, the notion that climate change is real, and represents a danger, has been ringing in my ears since primary school. It has been clear and obvious to me that something needs to be done about the crisis my entire life. And it's the reason that a I founded a climate-tech company. This was not necessarily the case for my parents' generation, who received less education around the phenomenon of climate change. Though climate change and its threat were flagged by *big oil* itself as early as 1986 (and was predicted far earlier), the excitement of economic growth and prospect for increased

personal wealth overshadowed it while at the same time, the topic was actively discredited by the very same big oil companies (Griffiths et al., 1988).

It's hard to comprehend how differently the current youth perceive the situation. Not only is never-ending economic growth and even the drive to earn money over one's passions rejected by many of them, but climate change is seen an existential crisis, not just a noble cause. It's seen as a practical must for their very survival. Working to prevent it is simply a way of preserving even basic living standards for their future.

As these young brains climb corporate ladders and enter positions of political power, more and more confident and aggressive actions will be taken. The degree of these preventative actions will be in step with the increasing severity of climate change and perhaps even accelerate beyond it. In the eyes of the current youth, economic growth at the expense of our climate and equality in society, is seen as narrow-minded at best, criminal at worst. It's also not seen as a zero-sum game.

A good example of how enlightened, sustainability-positive mindsets have been adopted in the free market are the companies *Patagonia* and *Interface* (Harvey, 2020). Not only are they both now net-carbon negative but they integrate sustainability and circularity into everything they do. There are many other companies out there who are striving to do the same thing. Such purpose, as attested to by their employees and founders, not only makes everyone feel good but actually saves money for the companies and increases their market competitiveness.

Children today fear asking, in an apocalyptic future scenario, why on Earth their planet was sacrificed needlessly when so many obvious solutions exist to solve the issue.

Direct air capture and the cradle-to-cradle economy

The term *cradle-to-cradle* was coined by William McDonough in 2002 in his book of the same title. The book itself is printed on recycled plastic. It postulates how consumerism should be re-framed from a system that uses and then disposes of resources to one that 'upcycles' almost every material consumed.

Let us take a dishwasher for example. Typically, it will have a lifetime of ten years, after which it will end up on a landfill. In a cradle-to-cradle economy (otherwise know as a 'circular' economy), that washing machine would not by dumped at its end-of-life. The manufacturer instead or associated party would retrieve it, break it down into its component parts, and build an even better model out of it, or turn it into say, a refrigerator. This approach beats downcycling, where inherently we are in a race to the bottom. In a downcycling scenario, half the pieces of the dishwasher are disposed of, the plastic is turned into straws and the metal is sold as a commodity.

Such a circular economy is arguably the only way forward for our society if we acknowledge that Earth's resources are finite and may not last thousands of years. We must also acknowledge that they will not be able to sustain unlimited population growth. One of the best examples of the circular economy in action today is rare-earth metals. A large portion of these is now retrieved from used electronics (including iPhones) to be redeployed in new designs (Apple Inc., 2022). The circular economy is also gaining ground in plastics, where over 9% of the material is now recycled globally (Bremer, 2022). Clean energy, including solar and wind, as effectively tapping into an unlimited resource, may also be described as circular.

Beyond energy, commodities and physical goods, another circular resource is carbon emitted into the air. Unlike carbon from the ground used to produce fuel and plastics, recycling carbon from the air is in fact a sustainable, long-term method of using the commodity. The net contribution to the atmosphere if those products were burned again, ends up being close to zero. In fact, technology to recycle atmospheric CO_2 is now a critical component of all IPCC global warming mitigation scenarios (Guel, 2022).

What can we make from carbon? Today industrial carbon is used in the millions of tons a year to accelerate the growth plants in greenhouses, to carbonate drinks and to make water potable. It represents a multi-billion dollar industry which includes players such as *Linde* and *Air Liquide*. But the use-cases for CO_2 go far beyond these relatively small-scale applications. Atmospheric CO_2 can be used to create 'synthetic fuel' e.g., methanol, by combining carbon from the air with water over a catalyst. Synthetic fuel will displace traditional fossil fuel in hard to electrify sectors such as aviation. Imagine if fuel for our planes could be made from atmospheric carbon? That would mean anything we burn will represent a close to net zero emission. CO_2 also enables stronger, higher quality cement through a mineralization process. Almost thirty billion tons of cement and aggregate are deployed in our built environment every year. The utilization and sequestration potential of CO_2 in cement alone is 3 billion tons a year (Woodall et al., 2019).

Combined with the ever growing market for carbon credits, Carbon Capture and Utilization (CCU) powered by DAC (capturing it from the air) will represent an economic boom equivalent to the discovery of oil in the twentieth century. The application of CCU to mineralization alone (and as a result the sale of carbon credits and CO_2 as a commodity), is estimated to reach one trillion dollars in market size by 2050 (Sick et al., 2022).

Fortunately, as part of this new industry, we will become (and already have become) very good at actually drawing CO_2 out of the air. The first DAC company was founded in 2008 and only a handful existed until the late 2010s. With the climate emergency crystalizing for ever more entrepreneurs, over one hundred DAC companies now exist, exploring a wide array of novel and effective technologies to capture carbon. The cost of implementation has long impeded the development of DAC and still does today. But with so much creativity and competition, radically new technologies will emerge to make the process vastly more efficient. Even industry pioneers such as *Climeworks* and *Skytree*, who have adopted and adapted proven technologies, and are now installing systems around the world, continue to drive down costs through manufacturing and process efficiencies (Shulman, 2024; Twindale, 2024).

The sector is also well funded by private and public capital, and powered by ever higher prices set for carbon credits. A ton of DAC-captured carbon has been set at > $180 in Biden's recent Inflation Reduction Act (The Whitehouse, 2023). These credits can be sold many years ahead, allowing for the early release of funds needed to build the carbon capture hubs themselves. As the sector develops, and the cost of DAC processes reduce, as was the case for solar energy, our

ability to remove CO_2 from the air will continue to improve. With all the initiatives and ideas being pursued today, it's hard to imagine that we will not have the capability to draw down CO2 cost-effectively and at a planetary scale, by 2050. And such a capability, while not being a silver bullet to climate change, will certainly be helpful in staving off the worst of it.

Space exploration

Starship had its third test flight on the morning of Friday, March the 14th, 2024. Not only was hot-staging, the riskiest part of the ascent according to SpaceX, again a success but the second stage made it into space. Both stages eventually self-destructed due to instability on re-entry. Nevertheless, Starship 3 was the largest man-made object ever to make it into space. The largest rocket ever built (larger and more powerful than Apollo's Saturn V), was propelled by 36 simultaneously firing Raptor engines, which were developed and manufactured in-house by SpaceX. The mass-to-orbit capability of one Starship has the potential to ferry such a large amount of hardware to space that it would represent a step-change in today's launch capabilities. And its full reusability has the potential to enable the lowest cost per kilo to orbit ever seen, less than the current price point by an order of magnitude.

Simply put, SpaceX's Starship will revolutionize Low Earth Orbit (LEO), allowing space stations and orbital laboratories to be built at an unprecedented rate. Starship will also be the workhorse of Artemis' Moon landing program, scheduled to begin in 2025. And SpaceX itself has ambitions to explore and colonize Mars. To achieve such low costs, the company has leveraged superior computing power than was available during the original Moon program, allowing for lighter weight and more capable space systems (think miniature satellites, or real-time computing power for automated landings), as well as highly efficient, mass-manufacturable Raptor rocket engines.

SpaceX's conservative target of one launch per day of its Starship rocket is looking ever more achievable (Scoles, 2022). At that rate, and assuming a payload capability of 150 tons per launch, everything that humanity has ever put into space since 1957, the entire mass of everything ever in orbit today (about 7,500 tons), could be ferried to space in less than eight weeks by a single vehicle (Shoots, 2015). Private organizations and governments will be a large driver of this activity. Starship, as with Falcon, currently the dominant launcher in the market, will be contracted and leased for missions separate to those being driven by SpaceX. All this takes no account of China's plans for space which includes exploration of the Moon.

What has all this got to do with climate change? Well, a large portion of our current economy and our efforts to fight climate change are driven by technology derived from the space sector. Solar panels, first deployed in space by NASA in 1958, were drastically improved over the 1950s and 1960s to meet the harsh conditions of orbit and the need for remote power (NASA, 2015). They have since been commercialized and now represent the cheapest form of electric energy available to us today. Our ability to navigate streets, order food on Uber Eats and predict if it will rain tomorrow, is powered by hardware 400 kilometers or more above our heads. And many other useful technologies we see in daily life, was developed by scientists and engineers originally inspired to get into STEM by the prospect of space exploration. It is thus reasonable to assume that the imminent boom in space will enable new and novel technologies that will support our fight against climate change in unforeseeable but effective ways.

Furthermore, the economic costs of climate disasters, already tallying to $313 billion in 2022, will only increase and will dwarf any investment we put into either space or, for that matter, fighting climate change (Lörinc, 2023). Those who believe that space exploration is a misplaced effort which is too far removed from real-world problems, are assuming a zero-sum equation. It's telling that the same person who made SpaceX one of the most capable aerospace companies today, is the same person who single handedly spurred the electrification of the automotive industry—itself resulting in massive reductions in carbon emissions. It should also be noted that without space exploration and the Earth observation it has enabled, we would be a lot less aware of climate change itself.

Levelling up

There are overlooked and even unrecognized factors at work today that will level-up our efforts against climate change in the future. These may stem from societal trends, AI or even space exploration. But the fact remains that we can win this battle with the current means at our disposal. Where there's a will, there's a way. If great societal change was enacted, essentially on a dime, due a biological threat, and as we can see, society recovered and is now prospering, the same is possible for the existential threat that is climate change. And thankfully, as its consequences are felt more widely and severely by populations around the world, politicians will be forced into ever greater, more ambitious action.

Clearly there are also many obvious and non-obvious natural and societal trends that *adversely* affect our fight against climate change. These include;

- an ever increasing global population
- the rapid industrialization and growth of less developed nations
- the natural 10–15 year lag between when a GHG is emitted and the full force of its warming effect on the planet
- negative, reinforcing climatic feedback cycles such as less ice coverage => less solar radiation reflected => faster warming of the sea => less ice coverage. Or permafrost melt => more methane released => warmer temperatures => more permafrost melt.

We're in a fight against time – a balancing of opposing forces. The planet will be absolutely fine. It's really about how well its species, including humans, will survive dramatic changes in their weather systems. Eventually our planetary system will stabilize. If we are no longer around, new species will evolve.

It all boils down to the individual. How we act and the values we honor, is a decision. How much effort we put into ensuring a safe and stable environment for our children, is a decision. How much as individuals we decide to care, is a decision.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MB: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

MB is the founder of Skytree and was previously employed by the company.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Amnesty International (2023). Global: ruling in favor of activists in US climate lawsuit sets historic human rights-based precedent. Available at: https://www.amnesty.org/en/latest/news/2023/08/ruling-us-climate-lawsuit-historic-human-rights-based-precedent/

Apple Inc., (2022). Apple expands the use of recycled materials across its products. Available at: https://www.apple.com/newsroom/2022/04/apple-expands-the-use-of-recycled-materials-across-its-products/

Bremer, C. (2022). *Plastic pollution is growing relentlessly as waste management and recycling fall short*. Bloomsbury: OECD.

Chu, A. (2023), Youth activists win landmark legal victory in Montana case. Financial Times. Available at: https://www.ft.com/content/801d100a-6854-421d-a570-4d1b4c4b29bc

Copernicus. (2024). Warmest January on record, 12-month average over 1.5C above preindustrial. Copernicus Climate Change Service (C3S). Monthly climate bulletin. Available at: https://climate.copernicus.eu/warmest-january-record-12-month-average-over-15degc-above-preindustrial

En-ROADS Version 23.11.0 (2024). Climate interactive & MIT Sloan sustainability initiative. Available at: https://en-roads.climateinteractive.org/scenario.html?v=23.11.0

European Commission. (2024a). EU emissions trading system. European Commission. Available at: https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en

European Commission. (2024b). Carbon Border Adjustment Mechanism. European Commission. Available at: https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

Evans, J., and Sourati, J., (2023). Accelerating science with human-aware artificial intelligence, nature human Behaviour, Report No. 1682–1696. Available at: https://www.nature.com/articles/s41562-023-01648-z

Ferguson, D. (2023). Ministers set to ban single use vapes in the UK over children addiction fears. The Guardian. Available at: https://www.theguardian.com/society/2023/sep/11/ban-on-single-use-vapes-in-uk-could-be-imminent

Griffiths, M. H., Bright, P. E., Homer, J. B., van Oudenhoven, J. A. C. M., and Waller, J. (1988). Shell confidential report "the greenhouse effect". (Shell international report no. HSE88-001). DocumentCloud. Available at: https://www.documentcloud.org/documents/4411090-Document3#document/p4/a415539

Guel, T. (2022). Direct air capture: a key technology for net zero. International Energy Agency. Available at: https://iea.blob.core.windows.net/assets/78633715-15c0-44e1-81df-41123c556d57/DirectAirCapture_Akeytechnologyfornetzero.pdf

Harvey, N. (2020). Beyond Zero. Available at: https://beyondzerofilm.com/

Keynes, J. M. (1932). "Economic possibilities for our grandchildren" in *Essays in persuasion* (New York: Harcourt Brace), 358–373.

Lörinc, M. (2023). Weather, Climate and Catastrophe Insight. Aon. Available at: https://www.aon.com/weather-climate-catastrophe/index.aspx

NASA. Vanguard Satellite: 1958. (2015). NASA. Available at: https://www.nasa.gov/image-article/vanguard-satellite-1958/

Noor, D. (2024). Why 2024 will be a crucial year for climate litigation.The Guardian. Available at: https://www.theguardian.com/us-news/2024/jan/22/climate-change-cases-2024-lawsuits

Our Children's Trust (2024), Our Children's trust. Youth v.Gov. Available at: https://www.ourchildrenstrust.org/

Pelc, K. (2022). *Beyond self-interest: Why the market rewards those who reject it*. Bloomsbury: Oxford University Press.

Rajabi, M. M. (2023). Carbon tax accompanied by a revenue recycling increases Australia's GDP: a dynamic recursive CGE approach. *J. Clean. Prod.* 418:138187. doi: 10.1016/j.jclepro.2023.138187

Scoles, S. (2022). Prime mover. *Science* 377, 702–705. doi: 10.1126/science.ade2873

Shoots, D. (2015). Orbital debris quarterly news, NASA Orbital Debris Program Office. Available at: https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv19i1.pdf

Shulman, M. L., (2024). Skytree latest news: introduces leasing program for direct air capture CO2 units. iGrow News. Available at: https://igrownews.com/skytree-latest-news/

Sick, V., Stokes, G., and Mason, F. (2022). CO2 utilization and market size projection for CO2-treated construction materials. *Front. Climate* 4:878756. doi: 10.3389/fclim.2022.878756

The Whitehouse (2023), Building a clean energy economy: a guidebook to the inflation reduction Act's Investments in Clean Energy and Climate Action (p. 67–70, Version 2). Available at: https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf

Trading Economics (2024), EU carbon permits, Available at: https://tradingeconomics.com/commodity/carbon

Twindale, S. (2024). Climeworks opens world's largest plant to extract CO2 from air in Iceland. Reuters. Available at: https://www.reuters.com/business/environment/climeworks-opens-worlds-largest-plant-extract-co2-air-iceland-2024-05-08/

United Nations. (2023). Synthesis report by the secretariat: nationally determined contributions under the Paris agreement, report no. FCCC/PA/CMA/2023/12, United Nations FCCC. Available at: https://unfccc.int/sites/default/files/resource/cma2023_12.pdf

Woodall, C. M., McQueen, N., Pilorgé, H., and Wilcox, J.. (2019). Utilization of mineral carbonation and products: current state and potential, (9(12) Report No. 2152–3878). Greenhouse Gases: Science and Technology. Available at: https://www.researchgate.net/publication/337733472_Utilization_of_mineral_carbonation_products_current_state_and_potential