Critical Issues for the Global Climate

Transcript of Lev Lafayette’s presentation to “Future Day 2026”
https://www.scifuture.org/events/future-day-2026/

Earth's Climate System

Earth has an "energy budget", consisting of the energy that the planet receives from the sun and a very minor contribution other sources (e.g., internal heat) and that is lost to space.. Solar irradiance is unevenly distributed which equatorial regions receiving a greater amount than polar regions that generates a dynamic climate system. Climate is represented as the synthesis of regional weather over time determined by the complex interactions of the climate system; the atmosphere, oceans, and land surface (Hartmann, 2016, pp1-23., Wallace & Hobbs, 2006, pp25-58., Marshall & Plumb, pp9-22).

Temperature is the most obvious variable, with variation in the atmosphere according to zones, seasonal variation modified by latitude, and atmospheric composition with water vapour holding particular importance. Almost all water in the system is surface water (oceans 97%, ice 2.2%, groundwater 0.7%, etc), including the cryosphere (snow, ice, etc). With the world ocean covering 71% of the planetary surface it is very influential in determining atmospheric composition with the particle exchange, especially the removal of carbon dioxide from the atmosphere and the release of oxygen. Ocean salinity contributes to water density, which drives the deep-ocean circulation critical for heat storage and transport and distribution of life-giving nutrients. The topography, vegetation and soil conditions of the land surface influences regional climate and for terrestrial life, temperature, soil moisture, and soil composition determine the potential for the biosphere.

The climate system is dynamic with internal variability and external forcings. Internal variability includes the interrelationship between convection, oceanic and atmospheric interactions such as the North Atlantic Oscillation, the El Niño–Southern Oscillation, the Pacific decadal oscillation, and the Atlantic Multidecadal Oscillation (Marshall & Plumb, 2008, pp31-60, pp139-161). These interactions can affect the climate for years or even decades, affecting surface temperature, redistributing heat, and altering the cloud, vapour, and distribution of ice and, through thermohaline circulation, variability in oceans by redistributing heat on a timescale over centuries. Internal variability can be contrasted with external forcings, both natural and anthropogenic, that change the energy budget of the planet. The main natural forcings are solar activity, greenhouse gases (GHGs), and volcanics. The main anthropogenic forcing is the caused by the additional release of greenhouse gases, especially carbon dioxide, into the atmosphere.

The Industrial Age

The rapid transition in manufacturing, agriculture, and information goods from craft production to mechanised production, "the industrial revolution" occurred between 1760 to 1840 (Horn et al, 2010), resulting in a sudden and rapid increase in production and population. For the purpose of changes to the climate system, this period marked the beginning of new chemical processes and the widespread adoption of steam power and the use of coke fuel. The ongoing process of the extraction and burning of fossil fuels (coal, oil, natural gas) mainly for electricity, heating, and transport has resulting in increases of CO2 and methane in the atmosphere of 48% and 160% respectively since 1750 (World Meteorological Organization, 2021).

For the purposes of measurement of the climate system, the industrial age also witnesses the introduction of instrument atmospheric and oceanic temperature records to the level of quasi-global measurements beginning in 1850 (Brohan et al, 2006). The instrument record provides direct observation rather than inferred Palaeoclimate proxy indicators, such as historical documents, tree rings and corals, the contents of ice cores (e.g., stable isotopes, salts and acids, trace gases), mountain glacier moraines, varved lake and ocean sediments, and borehole measurements (IPCC, 2001, p130-133). For the purposes of this inquiry, and with the benefit of the direct measurement correlating with the anthropogenic changes, the use of the instrument record has priority.

Ensemble simulations with forcing agents have been compared to globally averaged surface air temperature during the twentieth century (Meehl et al, 2004). Warming in the early twentieth century is explicable with the inclusion of natural forcings (mostly solar), whilst warming in late twentieth-century warming can only be explained by anthropogenic forcing (mainly GHGs). Whilst "a preponderance of La Niña events" (Held, 2013) generated brief pause in the first decade of the 21st century, the overall warming trend continued from 1980s, with each decade warmer the preceding, and with 93% of the warming going into the global ocean (Johnson & Lyman, 2020). Taken as a whole from 1850 to 2019, there is no significant contribution from internal variability or from solar and volcanic drivers. The summary statement of the IPCC (2021) gives a very clear overview:

> *The likely range of total human-caused global surface temperature increase from 1850–1900 to 2010–2019 11 is 0.8°C to 1.3°C, with a best estimate of 1.07°C. It is likely that well-mixed GHGs contributed a warming of 1.0°C to 2.0°C, other human drivers (principally aerosols) contributed a cooling of 0.0°C to 0.8°C, natural drivers changed global surface temperature by –0.1°C to +0.1°C, and internal variability changed it by –0.2°C to +0.2°C. It is very likely that well-mixed GHGs were the main driver of tropospheric warming since 1979 and extremely likely that human-caused stratospheric ozone depletion was the main driver of cooling of the lower stratosphere between 1979 and the mid-1990s.*

GHGs and the Carbon Cycle

Due to their molecular structure (electric dipole movements), a greenhouse gas absorbs longwave infrared radiant energy, emitting heat and increasing the rate the atmosphere absorbs short-wave radiation from the Sun. GHGs contain bonds that vibrate when they absorb infrared radiation, causing the molecules to become excited, and then in relaxation re-emit the absorbed energy as infrared radiation. This process traps heat in the atmosphere and contributes to the warming of the Earth's surface. The primary greenhouse gases, in order, are water vapour (H2O), carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and ozone (O3). Although making up only approximately 0.04 percent of the dry atmosphere. Water vapour varies from 0.1 to 4.2% and counts as part of the hydrosphere (McElroy, 2002, p34-36), noting that water vapour is not a direct forcing itself, but rather arises from forcings and has a feedback loop (Soden & Held 2006). GHGs are necessary for the biosphere and without them the the average temperature of Earth's surface would be about -18°C, rather than the present average of 15°C (Karl & Trenberth, 2003).

GHG	Pre-1750	to Recent (c2025)
Carbon dioxide (CO2)	280ppm	440ppm
Methane (CH4)	700ppb	1925ppb
Nitrous Oxide (N2O)	270ppb	338ppb

The increase of carbon dioxide and methane is particularly important in the context of the carbon cycle as it regulates the concentrations of these gases (Wallace & Hobbs, 2006, p41-45). The cycle refers to the movement carbon in the biosphere, the process of carbon sequestration to and release from carbon sinks. Atmospheric carbon is acquired from the biosphere (respiration and decay), from the crust (weathering), and the mantle (volcanism). The biosphere receives carbon through photosynthesis, passes it to the crust as burial, which can be passed to the mantle as subduction or returned from the mantle through sea floor spreading. Within the earth's crust carbon is found primarily as fossil fuels (natural gas, oil, coal) and calcium carbonate. This movement of carbon is reflected in the following (IPPC, 2007, figure 7.3).

Human Activity and Projections

Natural emissions (values from IPCC, ibid) of carbon dioxide from vegetation and land (439 gigatonnes) and oceanic release (332) contrasts with human emissions (an additional 29 gigatonnes, or 3.76% of the gross amount). However, land and oceanic natural absorption is actually (450 gigatonnes per annum and 338 respectively) than natural emissions. The net emission from natural sources is 0% of the total and natural absorption absorbs some 40% of human emissions. The net emission of human activity is c11.5 gigatonnes per annum, or 100% of the total. Whilst the carbon cycle and climate has been stable for thousands of years (Siegenthaler, et al, 2005), this is certainly no longer the case.

The following figures illustrate various changes in contemporary climate. Such graphical representations of often presented firstly to indicate that there is a potential problem, followed by an explanation of the causes. In this case, the system and the causes has been provided first; these figures are a selection the effects. Specifically (a) the CO2 levels with both proxy and observational data since the beginning of the Holocene epoch, (b) instrument records of temperature increase since 1850, (c) temperature increase of the last 2,000 years using proxies and instrument record.

GHGs can also be evaluated according to their atmospheric lifetime generating persistent effects after emission (Solomon et al, 2010). For example, about 50% of a CO2 increase will be removed from the atmosphere within 30 years, and a further 30% will be removed within a few centuries (IPPC, 2007). Whilst causing significantly more radiative forcing, a global warming potential (GWP) 84 times greater than CO2 in a 20-year time frame (Stocker, 2014 p.166), methane has an average atmospheric lifespan of around 12 years. Assuming no significant changes to GHG emissions, the global average temperature is expected to increase by approximately 3.3 to 5.7 degrees C by 2100, compared to pre-industrial levels (IPCC, 2021, p12-14)

Understanding the climate system, from broad concepts of the planetary energy budget, the addition of human greenhouse gas forcings into the atmosphere from industrial processes, and comparison with the empirical results allows climatology to answer the questions of detection and attribution. A summary response to these matters is provided:

To answer the detection question it must be shown that the warming that has been observed over the past century cannot be explained as change that has resulted from natural internal variability of the climate system, or from natural forcing such as volcanoes or solar variability. To answer the attribution question, it must be shown that the observed warming could not have occurred without the climate forcing that humans have provided. These questions are answered in the affirmative with multiple lines of observational evidence and with many experiments with global climate models. (Hartmann, 2016, p410)

Anthropocene Extinction Event

Palaeontology identifies five mass extinction events in the fossil record (Raup & Sepkoski, 1982) originally based on the geologically sudden loss of marine life, with subsequent calculations used to estimate the loss of species and genera diversity (e.g., Pimm et al, 1995., Simberloff, 1996, Sepkoski, 1996, etc). Whilst the exact quantity of species currently on the planet is unknown, among known species it is possible to calculate extinctions per million species-years (E/MSY) as a more accurate gauge in preference to absolute numbers with the fossil record providing background rates, albeit extremely coarse in time, space, and taxonomic level (Pimm et al, 2014). An alternative is the use of molecular-based phylogenies to calculate average diversification of speciation minus extinctions. Even given incomplete taxonomic knowledge, “extinction rates are likely a thousand times higher than the background rate of 0.1 E/MSY”, primarily the result of changes to biogeography. Further investigations (De Vos, et al 2015) develop median extinction rates of 0.023 to 0.135 E/MSY, with diversification rates of 0.05 to 0.2 per million species per year. Current extinction rates are calculated at 1000 times the natural rate with future rates likely to reach 10000 times higher.

The emphasis on biogeographical changes concurs with Spalding & Hull (2021) who nevertheless, take up the issue of the comparison of a background rate of extinction. They note that extinctions in the fossil record occur as pulses rather than within intervals characterised by the background rate. Their proposal of an alternative for future predictions and strong use of robust statistic methods leads to a conclusion that the Late Pleistocene stage is already highly anomalous in terms of an extremely short duration and high genus extinction; we are witnessing a transformation to the physical environment that is typically witnessed on a geological timescale and correlates with mass extinction. Whilst under some discussion, the evidence is in favour of rapid loss of biodiversity, in terms of populations, species, and biodiversity. Even when limiting extinctions to the background rates of for mammal and other vertebrate extinctions, based on "highly conservative" and "conservative" rates from the International Union of Conservation of Nature, a comparison of rates in the last century (since 1900 CE) and the last few centuries (1500 CE) indicates “an exceptionally rapid loss of biodiversity” (Ceballos et al, 2015).

These accelerated extinction rates closely correspond to the rise of industrial society and the accelerated rate of human development and impact on the environment. Whilst the extinction of species due to the effects of anthropogenic global warming are currently few - the Bramble Cay Melomys (melomys rubicola) is a notable exception (Waller et al, 2017) - human development includes population growth and consumption, changes to land-use (e.g., crop pollination, water purification), industrialisation, economic inequality between humans, and the rise of culturally and aesthetically important associations between humans with their non-human companions. Such developmental changes are readily evident in the geographic changes relevant to species. Making use of detailed classification of anthromes (Ellis, et al, 2010) on a global level it has been determined that in 1700 CE, approximately 50% of the terrestrial biosphere was wild and with an additional 45% in a seminatural state consisting of sparsely populated woodlands, with only 5% consisting of settlements, croplands and pasture. By 2000 CE, 55% had become agricultural and settled anthromes, less than 20% semi-natural and only 25% left wild. Needless to say, human development was also in the most ecologically rich areas as well; whilst wild barren land changed moderately (1700CE 17.22%, to 2015CE 12.14%), semi-natural land has declined substantially (58.68% to 24.25%) as croplands (2.52% to 14.70%) and pasture have increased (6.87% to 26.48%) (Ellis, Beusen, & Goldewijk, 2020).

Energy Trajectories

The main contributors to GHG emissions by activity include energy production (75.7%), agriculture (11.7%), industrial processes (6.5%), waste (3.4%), land-use change (2.7%). Global energy production has increased from a total of 22,869TWh in 1940 to 186,383TWh in 2024 (Energy Institute, 2025). Within the energy sector, the main industrial sources of GHG emissions are electricity and heat (29.7% of all emissions), transportation (13.7%), manufacturing and construction (12.7%) and buildings (6.6%) and fugitive emissions (greenhouse gases released during fossil fuel production or transmission, 6.6%). These industrial sectors are tied to consumer activities; for example, residential (12.5%) and commercial buildings (6.4%) use GHGs in electricity, gas cooking, and heating. Other major sources of energy-based GHG emissions include road use (12.2%), fuel combustion (6.4%), iron and steel production (6.1%), and other industry production (4.6%).

Correlating the industrial sources of GHG emissions with activities allows for consideration of viable renewable energy alternatives; for example, building design is an important mitigation technology, not just through using renewable energy sources for electricity, cooking, and heating, but through insulation, shading, and materials of long-lasting structures with embedded carbon (UNEP, 2022). The significant GHG emissions through transportation can be reduced through electric vehicles, mass transit, and urban design, although the explosive force of internal combustion engines will still have a role to play for moving massive loads over high gradients and there is always the concern of how the electricity is produced and battey production and disposal. In addition, without factoring in emissions costs as externalities, the current price of producing steel via coal furnaces is between 15% and 50% less expensive than hydrogen electric arc furnaces.

Whilst there is a modest trend toward reduced GHG emissions in energy, it is worth considering what the trajectory would look like without a transition, that is, if existing energy production were stablised at current values. In this situation, approximately 38Gt of CO2eq GHG emissions are added to the atmosphere each year, noting that energy demand (through economic development and population growth) would increase demand toward c45 Gt of CO2eq. The concentration of CO2 in the atmosphere, currently at 440ppm, would increase to to c700pm by 2100, and global warming increasing to 3.5 to 4.0 degrees higher than pre-industrial levels. Such a result would be extremely dangerous and damaging to human and non-human ecosystems, but is nevertheless the sort of possibilities that are explored by the IPCC with their Representative Concentration Pathways and Shared Socioeconomic Pathways are described (Riahi et. al, 2017. 153-168), in particular best matching somewhere between RCP 6.0, a high-emissions scenario, and RCP 8.5 a high-emissions scenario with additional growth.

Whilst somewhat outside of the scope of pure climatological considerations, but certainly within environmental considerations, is the question of production safety of energy, using the grim metric of lives lost per terrawatt hour (TWh) of energy produced, including the production, maintenance, and decomissioning of energy production sources, air pollution, and related disasters. Viewed with these considerations, brown coal is by far the most deadly source of energy, with 32.72 deaths per TWh, followed by black coal (24.62), oil (18.43), biomass (4.63), natural gas (2.82), then at a much lower rate, hydropower (1.3), wind power (0.04), nuclear (0.03), and solar (0.02). (EDIT Markandya & Wilkinson (2007); Sovacool et al. (2016); UNSCEAR (2008; & 2018)). The hydropower values are skewed somewhat by the significance of the 1975 Banqiao dam failures from Typhoon Nina, which killed an estimated 171,000 people. Nuclear is notably safe, even taking in consideration failures such as Chernobyl and its long-term effects.

RCPs and SEPs

Representative Concentration Pathways are climate change scenarios that described future greenhouse gas concentrations that correlate with expected temperature increases. Four RCPs, originally described as RCP2.6, RCP4.5, RCP6, and RCP8.5 represent changes in radiative forcing in Watts per metre squared from 1750 to 2100. In the most recent, IPCC Sixth Assessment Report, the RCPs are considered with Shared Socioeconomic Pathways, with the addition of three new RCPs, namely RCP1.9, RCP3.4 and RCP7. The first of these RCPs is based on limiting global warming to 1.5 deg C, the objective of the Paris Agreement, RCP4.5 represents and intermediate path, RCP 6 is a high-end emissions scenario, whereas RCP 8.5 emissions assumes a continued rise in emissions throughout the 21st century. Contrary to popular belief, RCP 8.5 does not represent a "business-as-usual" approach, but rather a high emission scenario of possible baselines which assumes high population growth, high economic growth reliant on fossil fuels with associated greenhouse-gas generation.

Temperature correlations with the RCPs by 2100 can be measured by mean and likely range. For RCP2.6 this is 1.0 degree C for mean and 0.3 to 1.7 degrees for range. In RCP4.5 these values are 1.8 (1.1 to 2.6), repectively, for RCP6, 2.2 (1.4 to 3.1) and finally for RCP 8.5, 3.7 (2.6 to 4.8). However, the RCPs also provide global mean sea level increase projections. The RCPs project with RCP2.6 a mean of 0.40 and a range of 0.26 to 0.55 in metres by 2100, with RCP4.5 a mean 0.47 and range of 0.32 to 0.63. With RCP6 it is 0.48 for the mean and 0.33 to 0.63 for the range, for RCP8.5 0.63 for the mean and 0.45 to 0.82 for the range.

Five major Shared Socioeconomic Pathways are described (Riahi et. al, 2017. 153-168). The first (SSP1) suggests a sustainable path with inclusive development within environmental boundaries and a much higher level of international and national economic equality that emphasises human well-being over material wealth. The second (SSP2) follows historical patterns in technology and socio-economic trends, with uneven growth and achievement in environmental goals. The third (SSP3) is mapped with increased national and regional rivalries with little concern for international development or the global environment. This will lead to high mitigation and adaption challenges. The fourth (SSP4) is mapped to highly unequal developments, with increased inequality between and within countries and high emissions, resulting in high adaption challenges, and finally, the fifth (SSP5), has high emissions, high global economic integration, high development, including climate change adaption, but also high challenges for mitigation.

Critical Issues: Concluding Remarks

The term 'critical' is no exaggeration. Whilst popular dictionary definitions associate it with "disapproving comments", what is meant is dealing with those issues that seek to identify a crisis [Habermas, 1975]. In medicine a crisis represents a point where, regardless of individual will, the physiological system of an individual is tested to capacity in its ability to heal. In literature, it is the point of the narrative where the protagonist either successfully confronts their antagonist, be that the setting, circumstances or another character or, in the case of tragedy, confronts their own weaknesses. In the environment, or social systems, it is also sensible to speak of crises, points in time and place where the capacity of the system is faced with a "life or death" test in its abilities to continue. All of this is elaborated in Habermas' Legitimation Crisis (the original German was "Legitimationsprobleme im Spätkapitalismus" in 1973). With regards to the environment, Habermas wrote the following:

Even on optimistic assumptions. however, one absolute limitation on growth can be stated (if not, for the time, precisely determined): namely, the limit of the environment's ability to absorb heat from energy consumption. If economic growth is necessarily coupled to increasing consumption of energy, and if all natural energy that is transformed into economically useful energy is ultimately released as heat... then the increasing consumption of energy must result, in the long run, in a rise in global temperature.... these reflections show that an exponential growth of population and production - that is, the expansion of control over outer nature - must some day run up against the limits of the biological capacity of the environment. (Habermas, 1975, p42)

Obviously this is all in the context of our current ecosystem and our current species. It is certainly true, based on the evidence that we have, that CO2 levels and temperatures were a great deal warmer in the past - in the era of dinosaurs, for example. But we are not dinosaurs and the rate of change we're experiencing is far in excess of anything that can be explained by natural variability.

Given this, what we are confronted with is, in computer science terms, "race conditions". Firstly is the total CO2 and other GHG emissions as one vector, which drives temperature increase, which is racing with the adoption of renewable technologies, carbon sequestration approaches (such as forestry), population stabilisation. There is another vector to this component, an unpopular consideration, on whether economic development needs to increase or decrease. Certainly huge portions of the world depend on economic growth for human welfare reasons, especially considering the global distribution of wealth. China, now the world's larger producer of GHG emissions (but without the historical debt) is also the world's largest producer of renewables, mitigation, and adaption measures. In fact, the principle of economic development with environmental protection is part of their constitution - the only in the world to do, based on the two mountains principle, expressed by Xi Jinping. The full slogan is "clear waters and green mountains are as valuable as gold and silver mountains" (Lǜ shuǐ qīngshān jiùshì jīnshān yín shān). Ultimately, the goal must be “net zero”, and achieving that with economic development is a “race condition challenge”.

The second "race condition" is whether the global political system will be able to introduce policies that embody such a principle, that provides economic growth for human welfare whilst giving sufficient environmental protection, "sustainable development", as the old slogan used to be. That is Shared Socioeconomic Pathways version 1, and Representative Concentration Pathways 1.9. This requires global agreements that are actually implemented, whether by goodwill or enforcement. The record of the Kyoto Agreement and the Paris Accords suggest that whilst these are positive steps, they fall well short of their own criteria and illustrate the enormous difficultly of reaching effective targets in an international framework. How do you get over 193 countries to come to a common agreement, especially in a context of rampant populist anthropogenic climate change denialism and how can such targets be implemented with limited means of enforcement? The evidence is not favourable for the political route, especially in countries that rely on capitalist democracy where ignorant populism combines with vested interests. More meritocratic, authoritarian, and engineering approaches seem more successful on the political route, whereas scientific research and engineering and ultimately market prices, has provided a positive route where renewable energy and electric vehicles are making rapid inroads replacing fossil fuel energy and fuel.

The most likely scenario is that the Earth is almost certain to surpass the 1.5°C warming threshold above pre-industrial levels within the next decade and to stay below 1.5°C is unattainable without improbable massive GHG reductions. Current and pledged policies indicates warming by 2.2°C to 3°C above pre-industrial temperatures by 2100, but much more likely at the upper end of the scale if not higher, given the historic failure of pledged policies. This still assumes that there is a high level of decarbonisation in electricity production in particular, but less so in other areas such as land transport, shipping, aviation, and industry. There are a large number of variables, the values are constantly changing, and even our knowledge of climatology - as good as it is - still comes up with some surprises, making the entire matter not just a "critical issue" but also a "wicked problem" - but one which is essential for our species, our ecosystem, and our welfare.