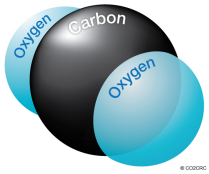
Energy Matters
Energy, Environment and Policy

Global CO2 emissions forecast to 2100

Posted on March 7, 2018 by Roger Andrews



In his recent post Euan Mearns projected global energy requirements out to 2100. In this brief post I apply Euan's methodology to carbon dioxide emissions, which are closely correlated with energy consumption. The projections show CO2 emissions peaking around 2075 under the UN low population growth scenario but continuing to increase through 2100 under the UN's medium and high population growth scenarios. The alleged "dangerous interference" threshold of 1 trillion tons of cumulative carbon emissions (3.67 trillion tons of CO2) targeted by the Paris Climate Agreement is exceeded between 2050 and 2055 under all three scenarios.

Figure 1 plots global CO2 emissions and total primary energy consumption between 1965 and 2016. The data are from the BP 2016 Statistical Review. Note that the CO2 data cover only emissions from fossil fuel combustion. Other greenhouse gases such as methane and Nox are not included:

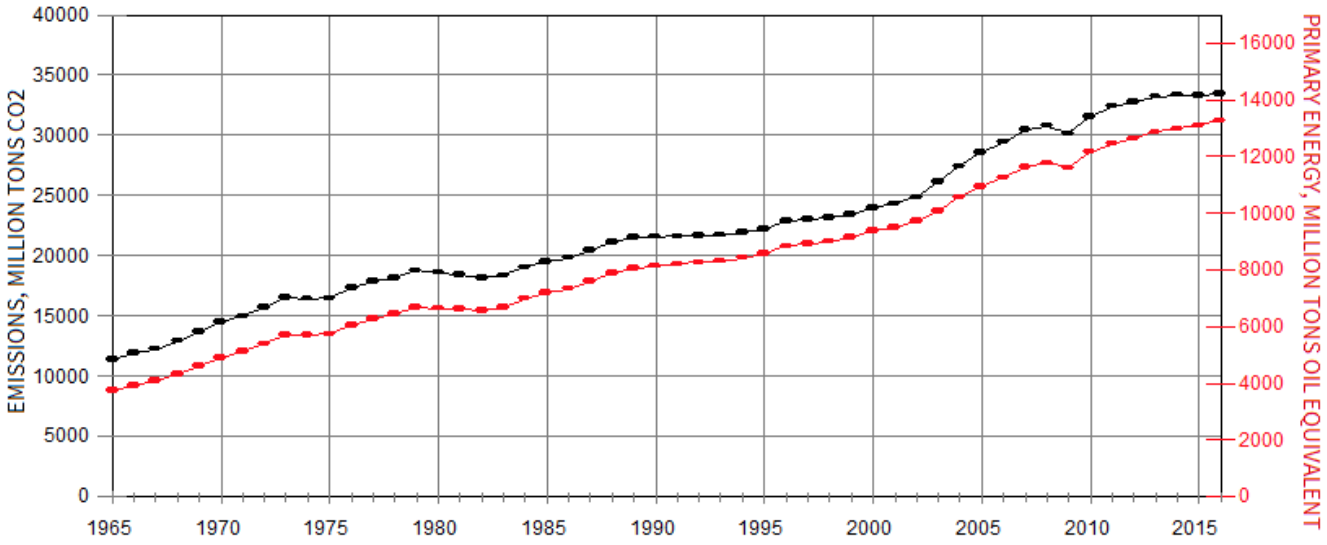


Figure 1: *Global CO2 emissions and primary energy consumption, 1965-2016*

The near-exact match between CO2 emissions and energy consumption (R^2 = 0.998) is obvious. What is not obvious is any detectable impact from the world's efforts to cut CO2 emissions, which began at Kyoto over 20 years ago in 1997. (The combination of flattening emissions and moderate economic growth after 2013 has been claimed as evidence that energy and emissions are finally becoming decoupled, but global CO2 emissions in 2017 have risen again – by about 2% over 2016 according to Carbon Brief.)

Figure 2 plots global per-capita CO2 emissions since 1965, calculated from the BP emissions data and the UN's global population estimates:

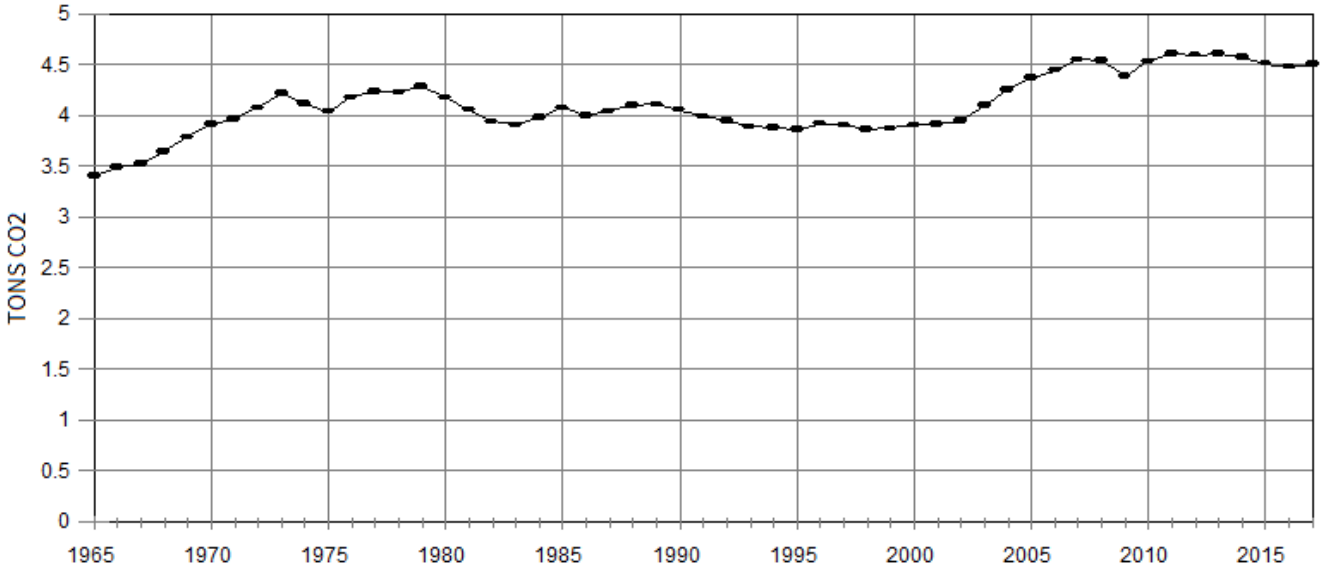


Figure 2: *Global per-capita CO2 emissions*

This plot is similar to the plot of per-capita energy consumption shown in Figure 1 of Euan Mearn's post, which we would expect given the close correlation between emissions and energy, but the trend is less steep. The likely reason is that the proportion of world primary energy supplied by low-carbon sources (nuclear, hydro, renewables) has increased from about 6% in 1965 to approaching 15% now. Nevertheless the overall trend is still upward.

Euan based his projections on a linear trend line drawn through all the data. I have done it a little differently, although with substantially the same result. First I discarded the data before 1982, which is distorted by oil embargoes and multiple recessions. After 1982 the plot divides itself into three periods: 1982-2001, when per capita emissions stayed reasonably flat, 2001-2007, when they increased by about 0.5 tons/capita primarily because of China's rapid industrialization and 2007-present, when they flattened out again except for the dip during the 2009 global recession. I have assumed that as other developing countries – notably India – follow China's lead we will see the same pattern repeat itself in the future, with a ~0.5 ton increase in per-capita CO2 emissions once every ~25 years. I have applied this as a linear increase of 0.02 tons/year for projection purposes. (A regression line fitted to the data after 1982 gives a gradient of 0.021 tons/year.)

Combining this linear increase in emissions with the UN's high, medium and low population growth cases gives the projections shown in Figure 3. Global CO2 emissions increase through 2100 in every case except the low population growth case, where they peak around 2075. These results are about what we would expect to see from a projection of this nature:

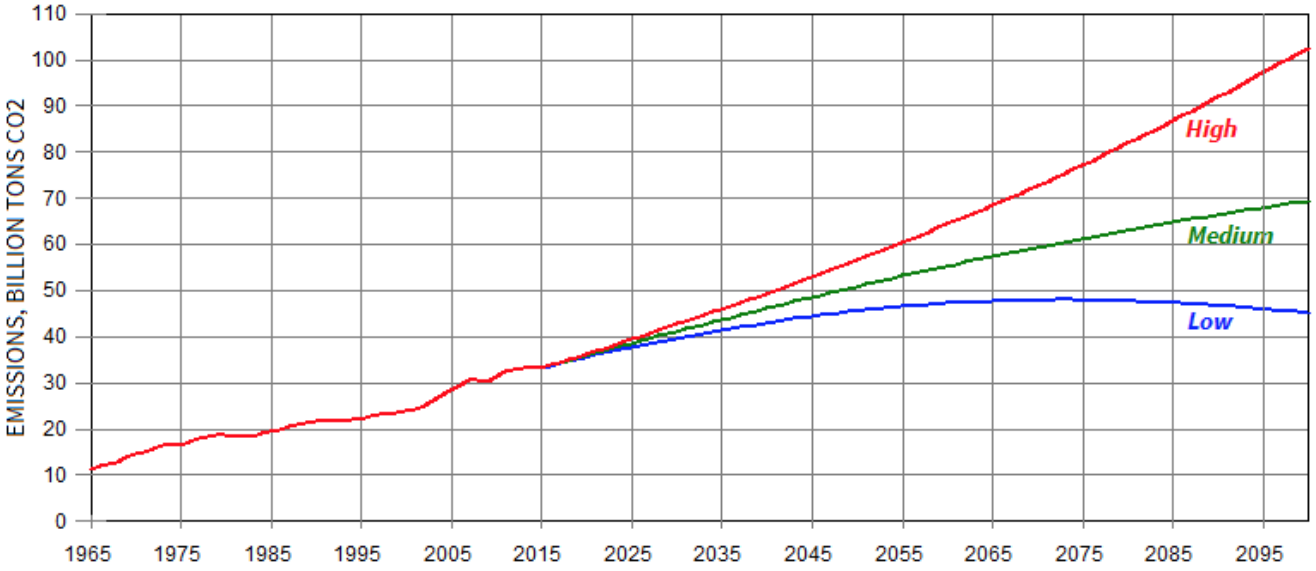


Figure 3: *CO2 emissions projections through 2100, UN high, medium and low population growth cases*

Of most interest, however, is when cumulative global CO2 emissions exceed the 1 trillion tons of carbon (3.67 trillion tons of CO2) threshold, which according to the IPCC will raise the Earth's surface temperature to 2°C above the pre-industrial minimum and trigger "dangerous interference" with the Earth's climate system:

> *The Fifth Assessment Report of the International Panel on Climate Change (IPCC) quantifies the global maximum CO2 the world can still emit and also have a likely chance of keeping global average temperature rise below 2°C above pre-industrial temperatures. It reports that the goal is likely to be met if cumulative emissions (including the 535 GtC emitted by the end of 2013) do not exceeed 1 trillion tonnes of carbon (PgC).*

So when will the 1 trillion ton threshold be exceeded? According to Figure 4 at some time between 2050 and 2055 regardless of which population growth scenario we use:

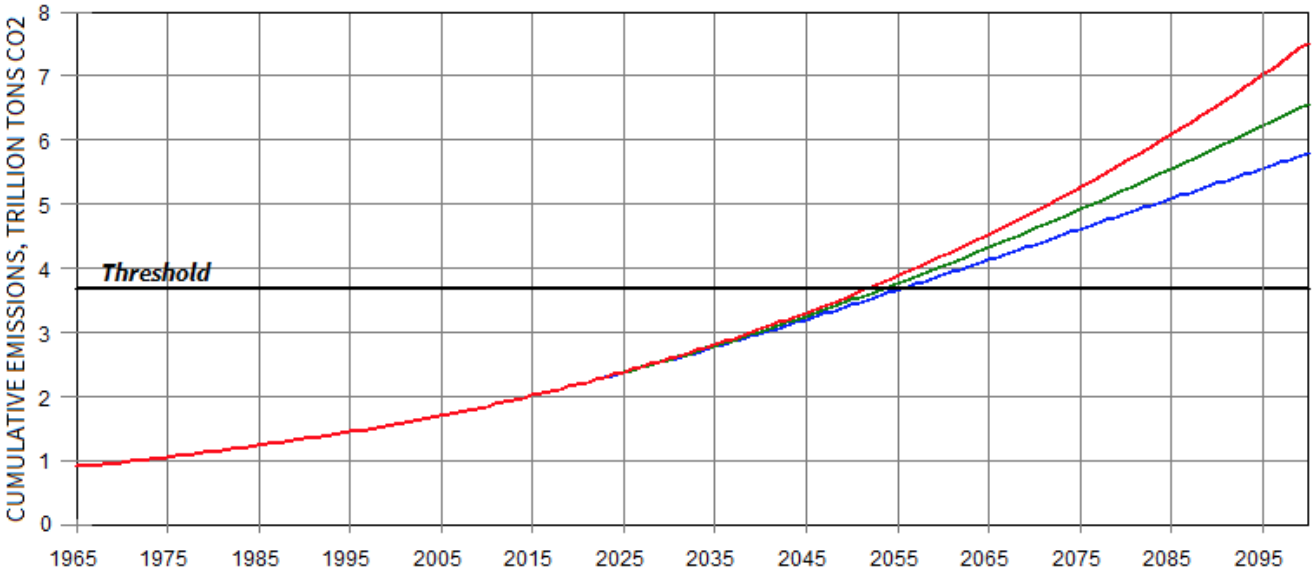


Figure 4: *Cumulative global CO2 emissions vs. the 1 trillion ton not-to-exceed threshold*

The 2°C threshold is backed up by no hard evidence, but it was nevertheless adopted as the world's official target in the Paris Climate Agreement, and the nations that are party to the Agreement, which include just about all of them except the US, are legally bound to pursue it:

> *At the Paris climate conference (COP21) in December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal.The agreement sets out a global action plan to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C.*

What would be needed in the way of emissions cuts to stay below it? Figure 5 superimposes Carbon Brief's estimates on the Figure 3 data. Note that by 2080 we are sucking CO2 out of the air:

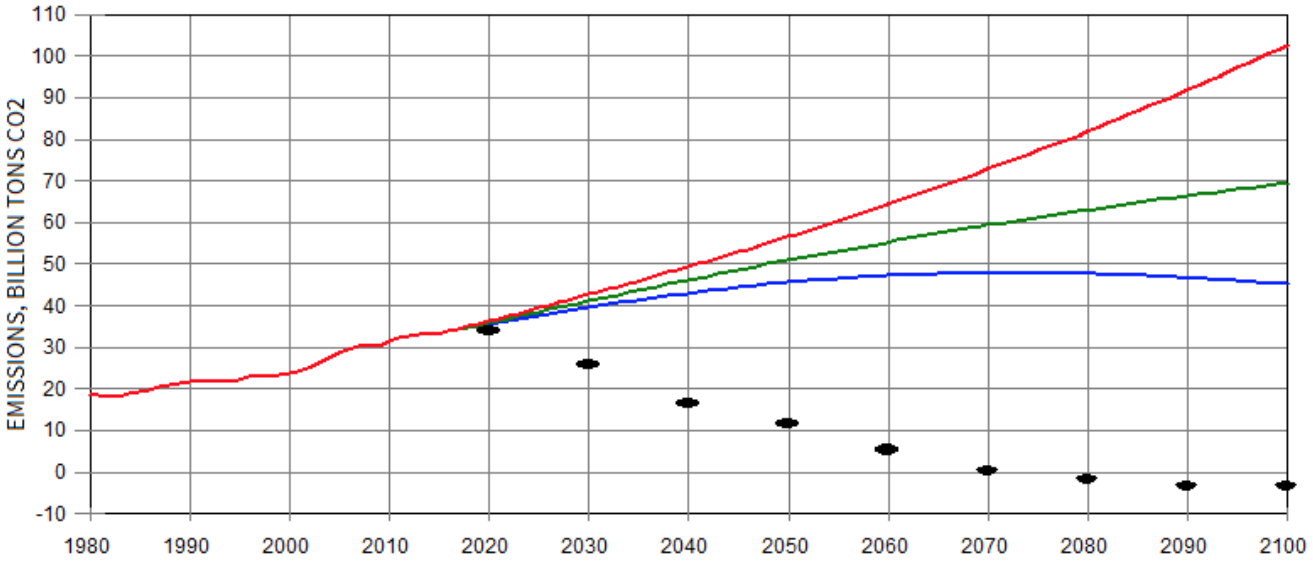


Figure 5: *CO2 Emissions reductions needed to stay below the 2°C threshold (black) superimposed on the Figure 3 projections*

How might the world achieve such massive reductions? Well, there's also a near-exact correlation (R^2 = 0.98) between global CO2 emissions and world GDP, and history shows that the only way of cutting CO2 emissions by any meaningful amount is by crashing the economy (the collapse of the Soviet Union in the early 1990s cut CO2 emissions in the former East Bloc states by almost 40% while the 2009 recession alone cut Spain's emissions by 15%). Enough said.

This entry was posted in Energy, Political commentary and tagged 2°C, bp statistical review, co2 emissions, per capita co2, population growth, recession. Bookmark the permalink.

39 Responses to *Global CO2 emissions forecast to 2100*

tonycarden *says:*
March 7, 2018 at 1:59 am

The only possible way to achieve these CO2 targets is by using Nuclear Power. Switching to Gas only delays the inevitable.
As for population growth.
In the Seventies when I was a young man there were discussions of the need for Zero Population growth. The population was then about 4 billion. The population is now 7.5 billion and the prediction is 10 billion by 2050, although some people say this will not happen. I disagree
Past performance is usually a good indicator of future performance especially when it comes human behavior.
After 2050 I would expect that the world population will continue to grow. The rate may slow however. As for a decline in population growth, remember that the worlds most populous country once had a one child policy. They have abandoned it.

louploup2 *says:*
March 7, 2018 at 3:26 am

Population biology, along with systems ecology and a number of other related disciplines, all point toward a population downturn. It could be rapid or it could be (relatively) slow, but down it will turn. That projection is a certainty on a finite world with diminishing available net energy and a series of wicked problems. The unknowns are how many and when the maximum will be reached, not if.

I think it's highly unlikely that human population will still be growing past 10,000,000,000 in 2050. Earth with a single species and its domesticated accessories constituting a majority of the faunal biomass is an ugly scenario.

Thinkstoomuch *says:*
March 7, 2018 at 2:40 pm

A funny. I don't know if you are right or wrong. I am not smart enough.

But you just gave a synopsis of an Isaac Asimov story from the 50's just substitute 7 billion for 10 billion. Of course it was about killing the animals in the last zoo. Not to mention that most of the food came from the ocean as algae. I think that particular story wasn't very prophetic.

Just saying,
T2M

jfon *says:*
March 8, 2018 at 10:15 am

The Chinese didn't abandon the one child policy because it wasn't working, but because it was too successful. All the other continents bar Africa, and most wealthy or middling countries bar a few oil sheikhdoms, are approaching or below replacement fertility.

Peter Lang *says:*
March 7, 2018 at 3:04 am

Roger,

Have you tried the calculations using the Kaya Identity?

"The Kaya identity is an identity stating that the total emission level of the greenhouse gas carbon dioxide can be expressed as the product of four factors: human population, GDP per capita, energy intensity (per unit of GDP), and carbon intensity

(emissions per unit of energy consumed).[1] It is a concrete form of the more general I = PAT equation[2] relating factors that determine the level of human impact on climate. The Kaya identity is both simple and tricky, as it can be reduced to only two terms, but it is developed so that the carbon emission calculation becomes easy, as per the available data, or generally in which format the data is available."

https://en.wikipedia.org/wiki/Kaya_identity

Roger Andrews *says:*
March 7, 2018 at 1:56 pm

No, I haven't. But feel free to give it a go yourself.

For the information of readers who may not be familiar with it, the Kaya Identity is expressed as:

F = P * G/P * E/G * F/E

where:
F is global CO2 emissions from human sources
P is global population
G is world GDP
E is global energy consumption

And when you cancel out the common terms in the numerator and denominator you get

F = F

Peter Lang *says:*
March 7, 2018 at 9:26 pm

In any correct equation the units have to balance on each side of the equation. That's basic physics, engineering, whatever.

The point is that the Kaya Identity is used to calculate emissions and to identify the least cost ways to reduce emissions. It's widely used by economists, policy analysts, IMF, World Bank, IEA, etc.

Here are some slides by Roger Pielke Jr. (he has many papers discussing how much GHG emissions can be reduced realistically. Including showing that the rate of GHG emissions reduction per capita and per GDP decreased when we started trying to interfere to reduce emissions intensity.

See Slide 9 here:

https://crawford.anu.edu.au/coombs/events/the_climate_fix/Roger_Pielke_PL_The_Climate_Fix_slides%20.pdf

It's surprising you didn't mention Kaya Identity or come across it in your research (?) for this post.

Roger Andrews *says:*
March 7, 2018 at 11:12 pm

I didn't mention the Kaya Identity because it had no bearing on the post, which as I said right at the beginning simply replicated the methodology Euan used in a previous post.

I've also known about it for some time. .

rogerglewis *says:*
March 7, 2018 at 5:58 am

This is a very informative and readable discussion built on an equally provocative and easily understood Article . Dr Tim Morgan has developed a Surplus Energy Economics DataBase (SEEDS) which looks at EROEI metrics across the Worlds major economies and contrasts it with Economic activity.

https://surplusenergyeconomics.wordpress.com/2018/03/06/121-interpreting-the-post-growth-economy/comment-page-1/#comment-5947

#120: The need for new ideas
Posted on February 23, 2018
PLANNING THE POST-GROWTH SOCIETY

”This article explores an issue that is always at or near the centre of where the economy is going. Worldwide, the long years of growing prosperity are over, and this change fundamentally invalidates many things that government, business and the public have always taken for granted.

The reason why growth is over, of course, is that we no longer have access to cheap energy. Where geographical expansion and economies of scale once drove down the cost of accessing energy, the driving factor now is depletion, which is pushing costs upward, and is doing so in an exponential way.” Dr Tim Morgan.

The same question of Post Prosperity/The end of Oil or The End of Growth was also recently Started at the RIchard Murphy Tax Research Blog http://www.taxresearch.org.uk/Blog/2018/02/27/is-post-growth-capitalism-possible/

The problem is getting out in the wild and it is fair to say the Problem, and it is a problem is being BrainStormed.

This Book is an easy read and the examples are very intuitive as they break back to the idea of how many 40 watt light bulbs different energy solutions break down as in per capita energy resources.

http://www.withouthotair.com/cL/page_370.shtml

There are some very good Sites which have well-embedded energy databases particularly in the Construction industry which uses 48% of global energy annually building and running domestic and commercial property.

http://symposium.arch.tamu.edu/2017/ Project Summary: Buildings consume approximately 48% of global energy each year in their construction and operation alone adding proportionally to global carbon emission.

The problems in Political Economy as it stands presently and the question of future Political Economy based upon future Energy realities are I think helpfully separated which is something Prof. David MacKay is very successful with, in his presentation of the question.

The Problems are only weakly related with respect to future solutions and breaking the process into 3 parts is useful rather than lumping them all together. It is clear that the existing Form of Market economy and political economy is not able to solve the problem at stage 3 (I.E Post 2050 post-Oil Economy)

Stage 1 requires a reform of the existing paradigm which involves facing up to the broken debt-based money system. Pension provision, the sovereign debt crisis and Public debt crisis are all addressable and will see improvements even within the deteriorating Cost of energy inputs as a share of output. We could call this stage lets fix what we know is not working.

Stage 2 covers the Post Financialised (Big Bang Experiment) period to the oil running out in 2050.
This requires a much more long-term investment horizon and complicating the energy mix by overstating the ”Climate Change question** seems to be counterproductive, again I like the way Prof David Mackay dealt with the question including stating the necessities of **Clean Coal and Nuclear”. In this stage, we will be implementing ideas previously barred due to the denial inherent in clinging to a failing system.

Stage 3 Post 2050, This part is much easier than Stage 2 and stage 1, in my opinion, the myth-busting and levelling out inherent in solving the political problems at stage 1 and the challenge to vested interests in stage 2 are by far and away the largest obstacles to getting down to Brass tacks in my opinion.

https://www.youtube.com/watch?v=GFosQtEqzSE

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rms *says:*
March 7, 2018 at 8:25 am

"The near-exact match between CO2 emissions and energy consumption (R2 = 0.998) is obvious.". Could it be BP used energy consumption in their formula to compute CO2 emissions, hence the correlation?

Roger Andrews *says:*
March 7, 2018 at 1:37 pm

Electricity sector FF emissions are calculated from the amounts of coal, gas and oil burned in power plants. So there will be a 1:1 correlation if the percentage of FFs in the global energy mix doesn't change significantly, which it hasn't. The correlation would begin to fall apart if low-carbon sources began to replace FF in large quantities, but so far that hasn't happened either.

Willem Post *says:*
March 8, 2018 at 12:51 pm

Roger,

Fossil fuels have been 78 to 80 percent of total primary energy for at least 43 years, despite trillions of dollars having been spent on RE during the past 20 years.

It looks like there is plenty of FF for at least the next 80 to 100 years, albeit at higher prices.

Your analysis is for only FF emissions, which are only about 60% of all manmade emissions.

That means any projections regarding CO2 reductions need to be much steeper.

Considering the steepness of the FF CO2 reductions, which are impossible to implement, even steeper reductions would also be impossible, even if the entire world were to build only nuclear and hydro plants as of right now.

Roger Andrews *says:*
March 8, 2018 at 6:39 pm

Willem:

"Your analysis is for only FF emissions, which are only about 60% of all manmade emissions."

Just as a matter of interest, where does the other 40% come from?

Willem Post *says:*
March 8, 2018 at 10:17 pm

Roger,

The major categories are

CO2eq Emissions
Electricity and Heat
Agriculture, Forestry, Other land use
Industry
Transportation
Buildings
Other energy
World CO2eq; 51.7 b Mt in 2014, 51.8 in 2015, 51.90 in 2016, with a 1 – 2 percent jump in 2017

See URL which has other URLs.

http://www.windtaskforce.org/profiles/blogs/summary-of-world-co2eq-emissions-all-sources-and-energy-related

Willem Post *says:*
March 8, 2018 at 10:44 pm

Roger,

FF CO2 emissions are only about 36.4 b Mt, FF/51.9 b Mt, all sources = 70% of all manmade emissions in 2016.

Roger Andrews *says:*
March 9, 2018 at 2:54 pm

Willem:

The +/-60% of global CO2 emissions that come from FF burning are all that we can measure with any reasonable degree of accuracy. CO2 emissions from land use change, forestry etc. are basically guesswork, as are methane and Nox emissions expressed as "CO2 equivalents". And not all of them are man-made.

Leo Smith *says:*
March 7, 2018 at 9:38 am

How might the world achieve such massive reductions?

http://www.templar.co.uk/downloads/Beyond_Fossil_Fuels.pdf

Grant *says:*
March 7, 2018 at 10:13 pm

That's an interesting read Leo.

I wonder if it would be worth a short review document that considers whether any of the points you have covered have by now progressed to a point that some further clarity of likely political influence and direction can be observed?

Willem Post *says:*
March 8, 2018 at 12:54 pm

Léo,
Your reference is grossly optimistic and omits one small item. COST

roberthargraves *says:*
March 7, 2018 at 4:29 pm

Quoting Tony Carden, "The only possible way to achieve these CO2 targets is by using Nuclear Power."

We are working to accomplish this. There are two current impediments: (1) cost and (2) fear. We can generate electricity cheaper than coal using ThorCon liquid fuel fission power plants, which can be produced in existing world shipyards at the rate of 100 GW of generation capacity per year. Capital costs of $1.2 billion per GW lead to 3 cents/kWh electricity, cheap enough to undersell coal and LNG fired power plants, enticing developing nations to select the cheapest (non CO2 emitting) source, in their economic self interest.

Unfounded fear (and consequent expensive regulatory appeasement of the frightened) is based on mistakes and deception by early radiation scientists, rightly concerned about avoiding all out nuclear war. Now radiation regulations are continued and ratcheted even tighter by mindless government bureaucracies, international advisory bodies, and scientists unwilling to tell the truth, discredit their mentors' reputations, and be blacklisted for future research funding.

No one has been injured by spent fuel. Radiation hurt no member of the public at Three Mile Island or Fukushima. Only firefighters died of radiation at Chernobyl, though several children died from ingestion of radioactive iodine. Though Hiroshima and Nagasaki were destroyed by atomic bombs, these cities were rebuilt, and about 500 of the 10,000 survivors eventually died from radiation-induced cancer. Nuclear power is safe.

Here's a description of a plan to use liquid fission power plants to power up our world without burning fossil fuels, ending CO2 emissions.
https://atomicinsights.com/clean-doable-liquid-fission-lf-energy-roadmap-%E2%80%A8powering-world/

Here's are websites of medical professionals' organizations working to overcome the fear-creating regulatory models of the LNT (linear no threshold) model and the ALARA (as low as reasonably achievable) rules.
http://x-lnt.org
http://radiationeffects.org

David B. Benson *says:*
March 7, 2018 at 9:24 pm

Of the two websites listed at the end the first fails to properly render. The second
http://radiationeffects.org/
works fine and I have passed this along to other websites. Thanks.

Grant *says:*
March 7, 2018 at 10:44 pm

The first one works for me. I'm using Firefox.

Just thought I would check and let people know.

Roger Andrews *says:*
March 7, 2018 at 10:46 pm

All the links work OK for me.

Grant *says:*
March 7, 2018 at 10:42 pm

The battle against "the fear" might be a long one.

Some months after Fukushima I was with some expats I know in France and was introduced to one of their near neighbours – also an expat – who happened to be a very recently retired rather senior police officer from Northern UK. His family had been living in France for some years I was told. He commuted weekly.

The subject of Fukushima came up and I all expressed fear and concern.

I mentioned that at that point hardly anyone had claimed to be affected by radiation and it seemed unlikely that there would be huge problems (if any problems) compared to the devastation of the tsunami.

As only people used to being in powerful authoritative positions can do he puffed up his chest and very forcefully said "Let me tell you ...." and proceeded to tell all in the party that hundreds if not thousands had been killed the many more thousands would die horrible deaths in the future due to radiation effects.

Now quite how he was positioned to "know" things that were not being reported in the press went unasked. After all he was a very senior policeman who might well have special knowledge that was not to be shared with mere members of the public and certainly not with any attribution.

Looking back it seems safe to say it was just his need to be bombastic for some reason at that moment. However many people could be convinced by what he said and the way he delivered it and might never question the reality in the future.

I met him a couple of times socially over the next year or so in the UK but heard some time after that that my acquaintances in France had come the conclusion that it would be more comfortable to change their social circle and avoid contact when possible. I'm not sure why but I have to say I think they made a wise decision.

I tell the story because I think it highlights the difficulty of countering "facts" once they seem to have been set in people's minds by "authority". Generations of useful development could be lost before enough people work out that the benefits outweigh the fear that the real facts might (or might not) create.

Javier *says:*
March 7, 2018 at 10:46 pm

Interesting analysis, Roger.

I did a similar analysis a few days ago and came with a completely different answer. Clearly the result depends on the assumptions.

You have assumed an increase in per capita emissions and used UN population forecasts. I have taken a completely different approach.

I have looked at recent trends. Past emissions projections have failed greatly because the rate of increase in our emissions has been falling since the mid-2000s, having reached already its lowest 5-year average value since the early-1990s, over 20 years ago, and have almost stalled. As we only know reasons why this rate of increase in emissions should continue going down, a knowledge-based conservative forecast is that emissions growth should become negative (decrease in emissions), before 2050, and should continue being so for the foreseeable future, except perhaps for short periods.

The UN population forecast shows that there is a profound and inevitable demographic change taking place. The UN medium-variant projection shows every region except Africa reaching peak population by 2050. The aged >60 population is the fastest growing group and by 2050 all regions of the world except Africa will have at least a quarter of its population above age 60. It is doubtful that per capita energy use can maintain its rate of growth given that it is tied to economic activity. For countries with ratios of people aged 20-65 (working age) / >65 below 3 and decreasing, what it is observed is a decrease in per capita energy use with time. From the fossil fuel demand side, moving towards stable or decreasing population and decreasing support ratio (number of workers per retiree), is likely to reduce demand growth. From the supply side, coal production appears to have already peaked, and oil production is generally expected to peak within the 2018-2050 period for

a variety of reasons, including reducing energy return on energy invested (EROEI, manifested in increasing costs of production), energy transition mainly to gas, but also to alternative energy sources, and active global policies to reduce oil and coal burning.

Coal production peaked in 2013 and has declined 8.7 % in three years (BP Energy Review 2017), the biggest drop on record. At the same time there is an increasing trend in coal plant retirements reaching 30 GW/year (Shearer et al., 2017), meanwhile the coal plant implementation rate for the period 2010-2016 is only 37%, with most plant projects halted, cancelled, or shelved. From January 2016 to January 2017 the amount of coal power capacity in pre-construction planning decreased from 1,090 to 570 GW (Shearer et al., 2017). As coal is being increasingly substituted by gas and other energy sources, the 2013 Peak Coal could be long-term, or even permanent. If so, Peak Coal has taken place many decades earlier than forecasted.

Oil is the least abundant fossil fuel. Several signs indicate we are approaching the end of oil growth (Peak Oil). Oil is categorized by its density (specific gravity), and with time the proportion of very light oil from tight formations, liquid condensate from natural gas, and heavy oil, has been growing at the expense of more desirable and higher priced conventional oil. It is also clear to anybody that we would not have to resort to fracturing shale rocks with high pressured water to obtain low-producing wells that decline by 75% in just three years, if we could still get sufficient oil by more conventional methods.
The impression that peak oil is approaching is confirmed by analyzing oil growth curve. For the past 30 years oil growth has been declining from ~ 2 % to ~ 1 %. This is a period when oil production has not been constrained, and more oil could have been produced if more demand for it existed. The decline can be attributed to a multitude of factors, including global economy growth rate, increasing oil use efficiency, economic changes that reduce energy intensity, demographic changes, and active policies to reduce oil consumption. If this long term trend continues, peak oil is expected to be reached ~ 2065 when oil growth should cease, but linear trend extension is a poor way of forecasting. While it is hard to imagine realistic scenarios that would make us grow our oil consumption faster, there are several reasons why we might slow our oil consumption growth. Obtaining oil from more difficult geologic formations leads to a higher cost oil that, to be sustainable over the long term, must be adequately reflected in oil price, and should promote oil substitution. The net energy yield of our global oil operations is decreasing, becoming a less efficient, less competitive process. Concerns over CO_2 emissions are also driving oil substitution with policies that for example support the increase in electric vehicles.

Since only factors that should decelerate the growth in oil consumption can be conservatively anticipated, the conclusion is that Peak Oil can be reasonably forecasted to take place before 2050. Even if we think that Peak Oil will not change our civilization significantly, the lack of oil growth will have to be compensated by other energy sources, if global energy consumption is to continue growing unaffected. While our response to Peak Oil might be to increase our coal consumption, it is reasonable to assume that we will also substitute it by gas and other energy sources, leading to a decrease in CO_2 emissions. Climate change scenarios that take into account GHG emissions must factor the almost inevitable reduction in our CO_2 emissions during the 21st century to avoid being unrealistic.

Now comes the interesting part. What would happen to atmospheric CO_2 levels under a likely decreasing emissions scenario from 2050? This scenario approaches us to RCP4.5 that shows stabilizing atmospheric CO_2 at ~ 500 ppm (van Vuuren et al., 2011). However, carbon sinks have been a considerable source of positive surprises to climate researchers. First, it was the "missing sink" (Schindler, 1993), as it could not be explained where the CO_2 from emissions that did not remain in the atmosphere was going. Environmentalists were slow to accept that the biosphere was expanding and greening in response to increasing CO_2 and warming, despite the opposite effect being well-documented during glacial periods. Then climate scientists became worried that the land (Canadell et al., 2007) and ocean (Schuster et al., 2007) carbon sinks were saturating. However the opposite has been found, and sinks are actually increasing their rate of uptake (Keenan et al., 2016). If in the 1960's they were taking up ~ 40 % of our CO_2 emissions, they are now taking up ~ 55 % of our much larger current emissions (Hansen et al., 2013).

The reason why sinks are taking up more CO_2 from the atmosphere is that we are farther from equilibrium. Since atmospheric CO_2 changed very slowly before anthropogenic emissions from fossil fuels, it can be considered that sinks (K) and sources (S) were at equilibrium at 280 ppm ($\Delta K = \Delta S$). Due to warming the oceans release ~ 16 ppm/°C, so current equilibrium is ~ 290 ppm. Since current level (~ 400 ppm) is above equilibrium level, sinks are bigger than sources ($\Delta K > \Delta S$), and the bigger the difference from equilibrium, the bigger the difference between sinks and sources ($\Delta K - \Delta S$). If we stabilize emissions (E) at present levels, which is happening, the difference between sinks and sources will continue

increasing until it matches emissions (ΔK–ΔS = E), reaching a new equilibrium for constant emissions. Since we are ~ 120 ppm above equilibrium and sinks are absorbing 55% of our emissions (ΔK–ΔS = 0.55E), it can be calculated that for constant current emissions the new equilibrium lies at 220 ppm (120/0.55) above the present equilibrium value of 290 ppm, or 510 ppm. Given constant emissions at present levels, atmospheric CO2 should increase logarithmically towards 510 ppm. One of the biggest mistakes in the climate change debate is that we need zero emissions to stabilize CO2 levels. Due to carbon stores large size, sinks (particularly the deep ocean) can be considered unlimited for the amounts involved for any relevant period of time in terms of human policies. The planet has dealt with much higher perturbations to CO2 atmospheric levels in the past. Fossil fuel CO2 push is puny compared to igneous traps burning for tens of thousands to a million years.

So under my set of assumptions, CO2 emissions are going to stabilize not much higher than present levels at ~ 35 GT CO2 and start declining ~ 2050. This obviously means less energy per capita. CO2 levels should stabilize ~ 510-520 ppm by ~ 2075 and temperatures should stabilize ~ +1.5 °C (1.2 °C anomaly over 1961-1990 baseline) before slowly decreasing for ~ 200 years.

As always it is all in the assumptions and everybody should decide what set of assumptions looks more reasonable to them. One thing is clear, past performance is no guarantee of future results. The world is fast approaching very profound changes that are baked in the mix and will really put our assumptions to test. The future is very unlikely to look as the past.

Roger Andrews *says:*
March 7, 2018 at 11:22 pm

Javier: That's not a comment. It's a post. 😉

Could you provide the results of your analysis? I'd be interested in seeing them.

Javier *says:*
March 8, 2018 at 1:17 am

You are correct, it is part of the draft for my next post at Climate.Etc. I just mostly copy-pasted. It may change when it is done, and I would welcome comments. Most of the info for emissions is from BP energy review 2017 and Global Carbon Budget 2017.

Evolution of global emissions and IPCC emissions scenarios.
https://i.imgur.com/bISieKl.png
The decrease in emissions rate of growth since mid-2000s is clear and has reached the lowest level in 20 years. Why should it increase much if we are trying to reduce them?

Coal production and coal plant retirement
https://i.imgur.com/98wi7Dh.png
Peak coal took place in 2013. Most of the world, including China, wants to reduce coal. India wants to increase coal, but it is having problems to do so. The rate of decrease of the past 3 years is not sustainable, but it is hard to imagine that it will turn into a vigorous coal growth.

10-Year rate of increase in World Oil Production
https://i.imgur.com/aDEPfia.png
It is going down. It was collapsing after peak conventional oil, and the fracking revolution restored the previous rate. It remains to be seen how sustainable it is in the long term as they have accumulated a huge debt that they aren't paying. More expensive oil should further reduce growth rate. My guess is peak oil by 2030 at the latest.

CO2 Airborne fraction
https://i.imgur.com/UpmjbNZ.png
The sinks keep gaining on emissions despite our brutal increase. The moment we slow down they'll catch up and stabilize CO2 levels.

1900-2200 emissions CO2 levels, solar activity, and temperatures
https://i.imgur.com/yAdkkAU.png
This scenario has the following assumptions:
– A continuation of the CO2 emissions stabilizing trend observed over the past 7 years with a small declining trend of 0.3 %/year after 2050.
– An increase in solar activity peaking ~ 2080 and a decrease afterwards.
– Unsaturating carbon sinks for the period and amounts considered.
– A trend to equilibrate carbon sinks and sources at an airborne fraction close to zero.
Even if emissions are wrong by 20% that should not change the scenario by much. The fall in emissions after 2050 is likely to be much faster but I don't want to put a too optimistic scenario (or pessimistic from a fossil fuel point of view). In any case CO2 doesn't have much effect on temperatures.

Robery Lyman *says:*
March 8, 2018 at 5:09 pm

It seems that those who continue to project the imminent decline in oil production or consumption just won't read the news. World oil consumption has been growing on average by 1.2 million barrels per day per year since 2008, probably the fastest rate of growth over a comparable period since the 1950's. The International Energy Agency just published its Medium Term Oil Market Report projecting that, in the near term, that rate of increase will accelerate, and that, by 2013, global oil consumption will reach almost 105 million barrels per day. Interestingly, the IEA historically has always underestimated oil demand growth, so actual consumption could be considerably higher, assuming that much higher prices do not dampen it after 2021.

Javier *says:*
March 8, 2018 at 8:23 pm

> *It seems that those who continue to project the imminent decline in oil production or consumption just won't read the news.*

No, we don't, because the news are just a bunch of lies. Instead we prefer to look at the data, which I already posted.

https://i.imgur.com/aDEPfia.png

That's a 35 year trend that has gone through the 2008 financial crisis, the peak in conventional and the shale revolution without changing. None of those things were predicted by any government or international agency.

Also since mid-2015 C+C production has barely increased despite very low prices. I am not impressed by predictions of imminent accelerations.

Ed T *says:*
March 8, 2018 at 6:49 pm

Javier,
Is it true that light oils and condensates are less valuable than conventional crude? They need less processing than conventional to get the fuel grade products. Heavy crude less desirable for more processing and more low value co-products.

Javier *says:*
March 8, 2018 at 8:04 pm

> *Is it true that light oils and condensates are less valuable than conventional crude?*

It appears so.
"sweet shale oil produced from the Eagle Ford, Bakken and Permian basins aren't desirable feedstock for US refineries. Although they are technically "higher grades" of crude, they don't maximize the production of good stuff (diesel and gasoline) and produce too much of the very light stuff, which nobody wants."
http://www.oilsandsmagazine.com/news/2015/12/26/how-much-for-that-heavy-oil

Ed T *says:*
March 8, 2018 at 11:09 pm

That's value to refineries. An upstream operation can make money with simpler seperation before the downstream refiners start scrabbling over the fat: natural gas and lng are useless to refineries as raw feedstock but worth a few quid non the less. Lpg/propane/butane can be stripped before the refineries get their hands on the crude.

Javier *says:*
March 9, 2018 at 1:37 am

What refineries demand more usually conveys a higher price.

"The dramatic rise of US tight oil output had a profound impact makeup on the US import market, affecting the direction of crude flows all over the world.
Light sweet crudes that would normally command a premium over Platts Dated Brent have seen their values fall steadily, which has contributed to much narrower sweet and sour spreads.
Analysts have said one of the only avenues for these light sweet barrels to sell faster is for the price differentials of such crudes to fall even further, and make them more competitive with their sour counterparts.
This is starting to happen as the spread between light sweet and heavy crudes is narrowing as evident in Brent-Dubai EFS, which was over $2.5/b in early November 2016 and is now under $1.5/b."
http://blogs.platts.com/2017/08/14/light-sweet-crude-barrel-glut/

"Tight oil is currently more readily available for refiners in North America. However, tight oils present numerous challenges, which is why these crudes typically cost less than crude oils such as Brent (global crude oil benchmark) or West Texas Intermediate (U.S. crude oil benchmark)."
https://www.emerson.com/documents/automation/working-tight-oil-en-38168.pdf

Ed T *says:*
March 9, 2018 at 8:51 pm

Javier,
"as the spread between light sweet and heavy crudes is narrowing "

Light has a premium, all be it diminishing.

Robin Guenier *says:*
March 9, 2018 at 6:03 pm

Roger – you wrote:

"*The 2°C threshold … was … adopted as the world's official target in the Paris Climate Agreement, and the nations that are party to the Agreement …are legally bound to pursue it.*"

That's not so. The 2°C threshold is only an aspiration. And the EC statement you cited is wishful thinking: although the Paris Agreement imposes a strong moral (but not legal) obligation on the developed countries to reduce their emissions, it exempts the developing countries (responsible for 65% of global emissions) from any such obligation – legal or moral.

http://journals.sagepub.com/doi/pdf/10.1177/0958305X16675524
https://ipccreport.files.wordpress.com/2016/08/cop-21-developing-countries-_-2.pdf

Roger Andrews *says:*
March 10, 2018 at 12:01 am

Robin:

You're right that the 2C limit didn't become the target at Paris. It actually became the target five years earlier at the 2010 Cancun Conference, where "*Countries agreed a 'balanced package' that will keep temperature rise below 2C (3.6F). It stops short of a legal treaty, but commits all countries to cutting emissions for the first time under the UN.*" So I think "official" fits.

And as I stated in the text, the countries that have ratified Paris are legally bound only to pursue it, not to meet it. So this statement is factually correct too, although exactly what legal action will be taken against a country that is found guilty of not pursuing its target isn't spelled out.

Robin Guenier *says:*
March 10, 2018 at 1:40 pm

I disagree Roger. There are only three climate agreements with legal standing: the 1992 UN Framework Convention on Climate Change (the "Convention), the 1998 Kyoto Protocol and the 2015 Paris Agreement. Cancun has no such standing and, in any case, the 2°C target was only recognised (not agreed) at a working group held three months after Cancun: the *Telegraph* article that provided your quotation got it wrong. Therefore all that matters is the text of the Paris Agreement where the 2°C target is referred to in Article 2.1 (a). It's referred to there as an aim and an aim is not a commitment. Therefore it's not legally binding in any sense.

In my previous reply, I referred you to a paper by David Campbell – professor of law at Lancaster University. The paper is hidden behind an almost impenetrable paywall. But a pre-proof version can be accessed here: http://eprints.lancs.ac.uk/82508/2/What_Does_the_Paris_Agreement_Actually_Do_final_.pdf. I urge you to read it – especially the Abstract and the passage beginning "*However*" at the bottom of page 5 and ending "*or indeed any target*" on page 6.

And, in any case, as I explain in the paper I cited earlier, the Paris Agreement exempts the developing economies (responsible for 65% of global emissions) from any obligation – legal or moral – to reduce their emissions. Therefore there is no realistic likelihood of Article 2.1's 2°C aspiration even being addressed.

Roger Andrews *says:*
March 10, 2018 at 4:06 pm

The text of Cancun states as follows: *Parties agreed to* ***commit*** *…. to … a maximum temperature rise of 2 degrees Celsius above pre-industrial levels, and to consider lowering that maximum to 1.5 degrees in the near future* (my emphasis). The text of Paris states: *This Agreement … aims to (hold) … the increase in the global average temperature to well below 2 °C above pre-industrial level and (pursue) efforts to limit the temperature increase to 1.5 °C above pre-industrial levels.* If that does't make 2 °C "official" I don't know what does. 1.5 °C is your "aspiration".

I suggest that we defer further discussion on the meaning of "legally binding", which at the moment is unanswerable. (I was quoting other sources when I used the phrase, although I should perhaps have made that more clear.) As far as I know the only body presently empowered to impose penalties

on countries that miss their their emissions target is the European Commission, which can impose fines. But will it impose fines on Germany when it misses its 2020 target, which according to Reuters (link below) Germany has already abandoned? And will Germany in fact miss its 2020 target? Maybe not. There are all kinds of ways of fudging emissions data. I may discuss them in a future post.

https://www.reuters.com/article/us-germany-politics/german-coalition-negotiators-agree-to-scrap-2020-climate-target-sources-idUSKBN1EX0OU

Robin Guenier *says:*
March 10, 2018 at 5:07 pm

Roger:

(1) The Cancun outcome was not an agreement, so has no standing at international law – so it could not have established a binding commitment.

(2) The words you cite are not from the text of Cancun.

(3) It's true however that the 2ºC target was mentioned in connection with Cancun. But, as I said, that was in the Report of a working group meeting held in March 2011: http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf. Go to section 1, paragraph 4 (page 3) – you'll see it's referred to, not as something that was agreed ("the Conference of the Parties … *Agrees*"), but as a something only recognised ("the Conference of the Parties … *Further recognizes*"). In other words, no agreement – therefore no commitment.

(4) Your extract from the Paris Agreement is accurate. And, as you see, it "***aims*** *to strengthen the global response to the threat of climate change … by: Holding the increase in the global average temperature to well below 2ºC …*". [My emphasis] Yes, 2ºC may be "official" – but an aim is not a commitment. It is not therefore legally binding.

(5) The meaning of "legally binding" is not unanswerable. If a commitment is made in an agreement with legal standing, it's legally binding. Otherwise it's not.

(6) The body with authority to determine the responsibilities of the parties to an international treaty such as the Paris Agreement is the International Court of Justice. The European Commission may have authority in Europe – but not elsewhere.
