

Hamburg Aerospace Lecture Series

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- Professor Ian Poll

Are governments and aviation industry doing enough to fight climate change?





“Economic growth means an increase in real GDP – an increase in the value of national output, income and expenditure. Essentially the benefit of economic growth is higher living standards – higher real incomes and the ability to devote more resources to areas like health care and education.”

According to the OECD (Organisation for Economic Co-operation and Development)

“Economic growth is the most powerful instrument for reducing poverty and improving the quality of life in developing countries.”

(we are heading for trouble if we don't have economic growth)

Aviation enables economic growth (source IATA)



- Over 4 billion passengers and almost 60 million tonnes of freight per year
- Contributes about \$2.5 trillion (directly, indirectly and induced) to global GDP per year.
- Enables about £1 trillion in tourism GDP.

It is important to view this at the global level and not just from a European perspective. The developing economies and the poorest countries have the most to gain from aviation

What's the problem with the environment?



In a nutshell

Rising global mean temperature (*GMT*)

Warmer atmosphere holds more water

More water means more weather

More weather might mean climate change

What is the challenge?



- UN target is to keep *GMT* rise to well below 2° C.
- *GMT* rise is driven by net radiative forcing
- Many anthropogenic activities – including aviation – contribute directly to radiative forcing.

In order to meet the UN target anthropogenic net radiative forcing needs to be reduced and reduced quickly

What is global warming?



- *GMT* is determined by a balance between incoming solar radiation (short wave) and outgoing thermal radiation (long wave)
- Anything that reduces the outgoing radiation, e.g. increasing greenhouse gas, increases *GMT*
- Anything that reduces the incoming radiation, e.g. increasing Earth's reflectivity to sunlight (albedo), decreases *GMT*

Not all effects are bad

What has happened to aviation?



- Environmental lobby groups have targeted aviation.
- Aviation has been declared to be a particular threat to the environment.
- This message has been pushed by the media.
- Most people believe that aviation is bad for the environment.

However, is “Flight Shaming” fair or even accurate?



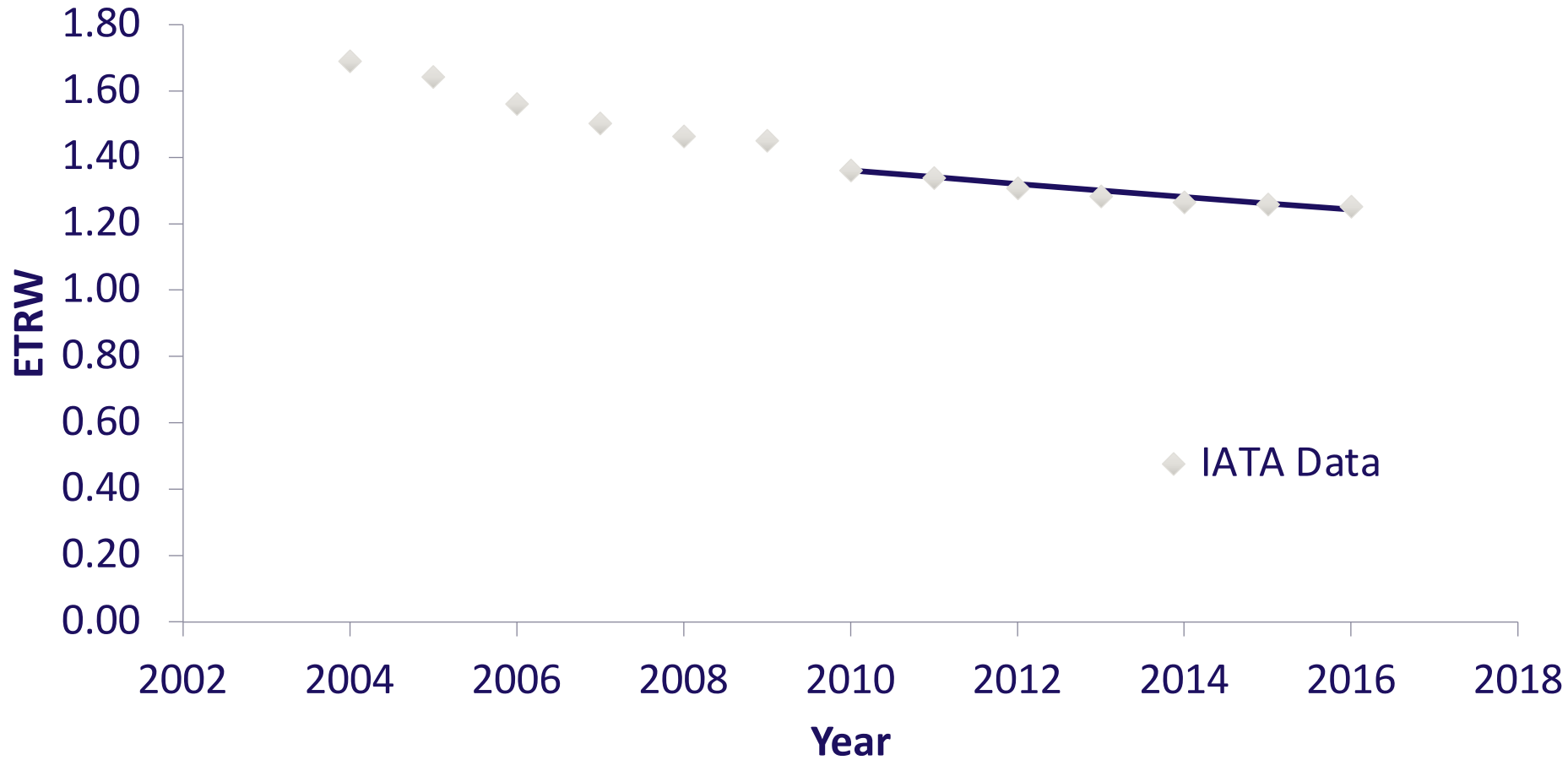
- Commercial aviation brings many economic and social benefits
- Many of the world’s poorest countries are totally dependent upon aviation.
- However, aviation is currently vilified as a “dirty” form of transport

So how does aviation compare with other forms of transport?

How efficient is the aircraft on the average?



Variation of global fleet average efficiency with time



What about the family car?



- 2 passengers
- 45 miles per gallon
- ETRW is about 1.2

Therefore, in terms of energy used aircraft are about the same as a car with two passengers averaging 45 miles to the gallon of fuel.

(no account is taken of the cost of providing and maintaining the roads)



What about the train?

- “Everybody knows” that trains are much better for the environment than aeroplanes, or cars.
- However, proving this is not straight forward.
- Rail track has to be laid and this involves vast quantities of concrete.
- Concrete is about 15% cement by mass
- Cement production releases 900 kgs of CO₂ for every tonne
- Globally, cement production releases about 4 times as much CO₂ per annum as the whole of aviation.

Therefore, before a single passenger is carried, there is a massive environmental down payment of CO₂,

Fair comparisons?



- Must include the huge down payment of CO₂ required to provide the roads and the rails.
- Should include damage to the countryside (loss of agricultural land, forests and natural habitat)
- Should include the noise pollution that affects 100s of 1000s of people
 - Should include the large number of cars with one occupant and the almost empty “off peak” trains.

Meaningful comparison between road, rail and air travel is difficult, whilst cars are worse, it is not at all obvious that trains are better.

The narrative needs to be changed



- Aviation is not the highly polluting form of transport that some environmentalists claim.
- Aviation allows travel over large distances at high speeds - >10 times faster than a car – >5 times faster than a train.
- Aviation needs no infrastructure linking departure and arrival points.

Aviation is such a large polluter, not because the machine is inefficient, but because so many people need, wish, or choose to make the journeys that are impractical by any other means.



- At the global level, CO₂ is the biggest problem.
- For most industrial activities, the elimination of carbon dioxide emissions is the biggest, often the only, way to reduce adverse radiative forcing.

However, this is not the situation in aviation



The gas turbine does three things

- Burning kerosene generates CO_2 , water and particulates
- High temperatures in the combustion chamber produce a mixture of nitric oxide and nitrogen dioxide, known as NO_x .

and

- Under the right atmospheric conditions, water vapour nucleates on the particulates and freezes, forming a contrail.

All these factors contribute to atmospheric radiative forcing

What is NO_x?



- Nitric oxide and nitrogen dioxide are not green house gases.
- However, by complex chemical reactions, they modify the level of pre-existing greenhouse gases ozone and methane.

The net effect of this interaction is to increase GMT



- If the contrailing aircraft encounters a region of the atmosphere that is super-saturated with respect to ice (*ISSR*) a persistent contrail forms.
- This contains millions of tons of ice from atmospheric water (much, much more than the water from kerosene combustion)
- Persistent contrails can last for several hours and over time may develop into cirrus cloud.

A persistent contrail is a major atmospheric effect with significant consequences

A common sight in the winter sky



.....and the spring sky





What do the contrails and the cirrus do?

- At night, some long wave (*LW*) radiation from the warm earth is absorbed by the ice so preventing it from escaping into space – a large warming effect.
- In daytime, *LW* radiation is still absorbed, but, in addition, some incoming, short wave (*SW*), solar radiation is reflected back into space. This can be enough for some daytime contrails to have a large net cooling effect.

With current global fleet operations, the long-term, net effect over day and night is a large warming



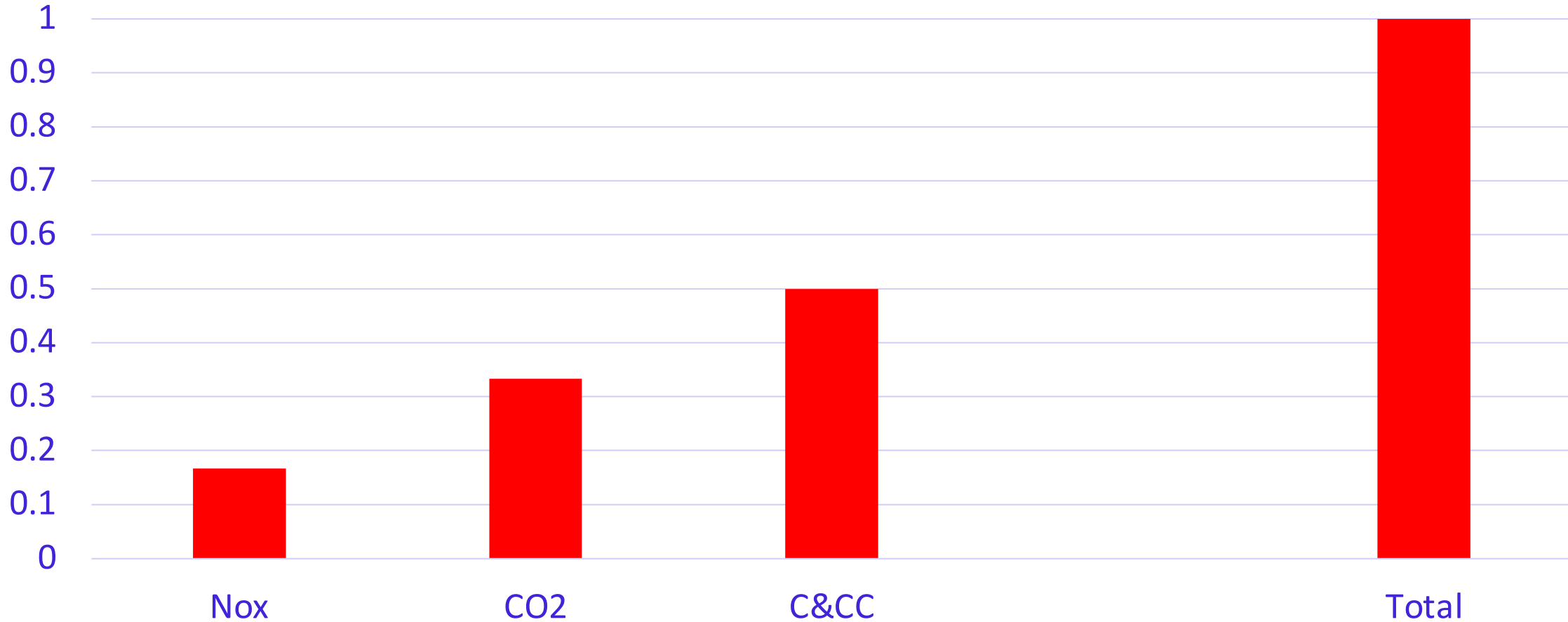
- Scientific understanding of the links between the non-CO₂ emissions and *GMT* change is incomplete, but developing rapidly.
- Nevertheless, the current scientific consensus is that the aviation's contribution to *GMT* rise through radiative forcing is roughly

1/3 CO₂, 1/6 NO_x and 1/2 contrail and contrail induced cirrus cloud

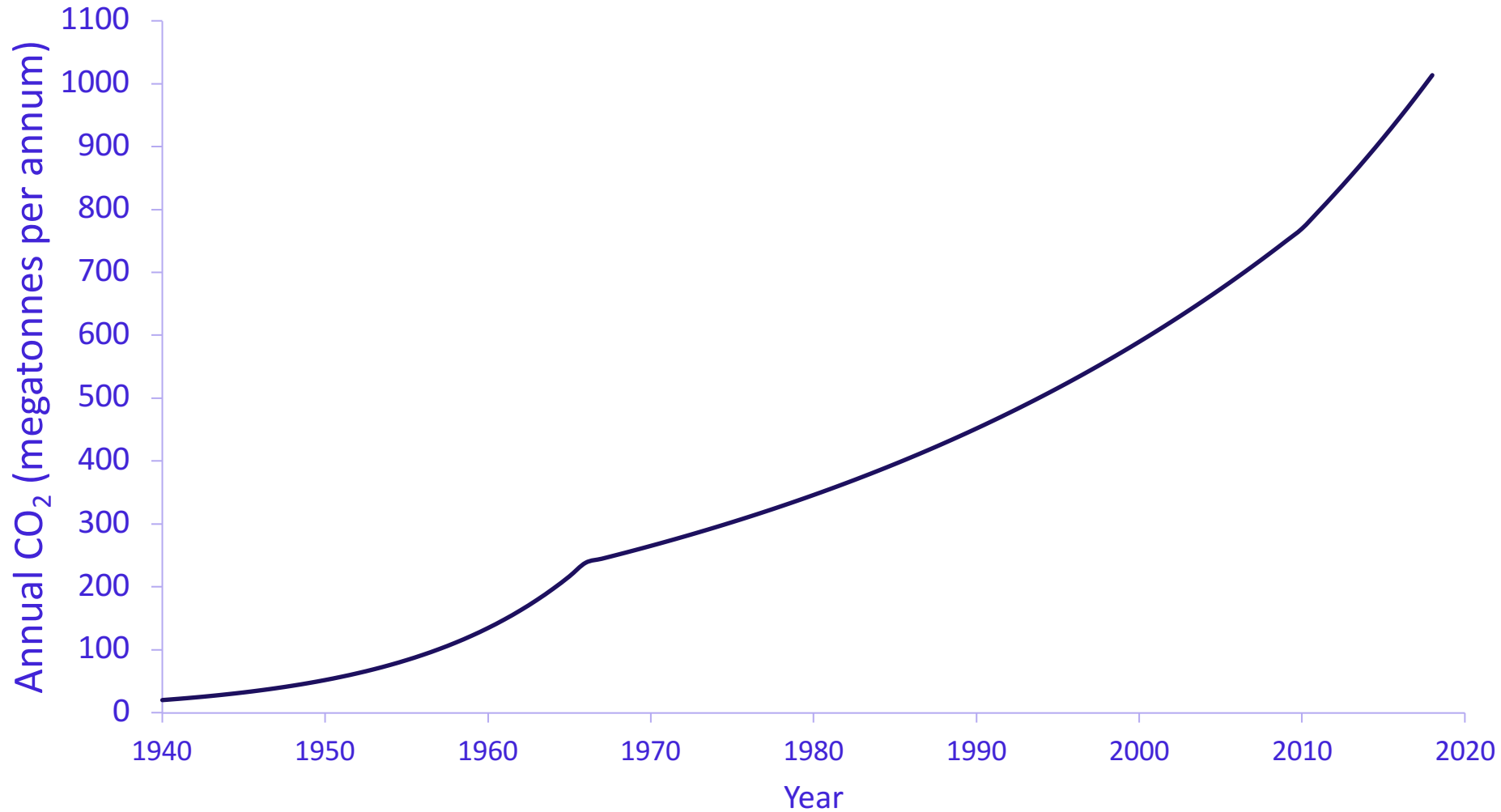
Aviation's current contribution shown in the "usual" way – all effects are warming



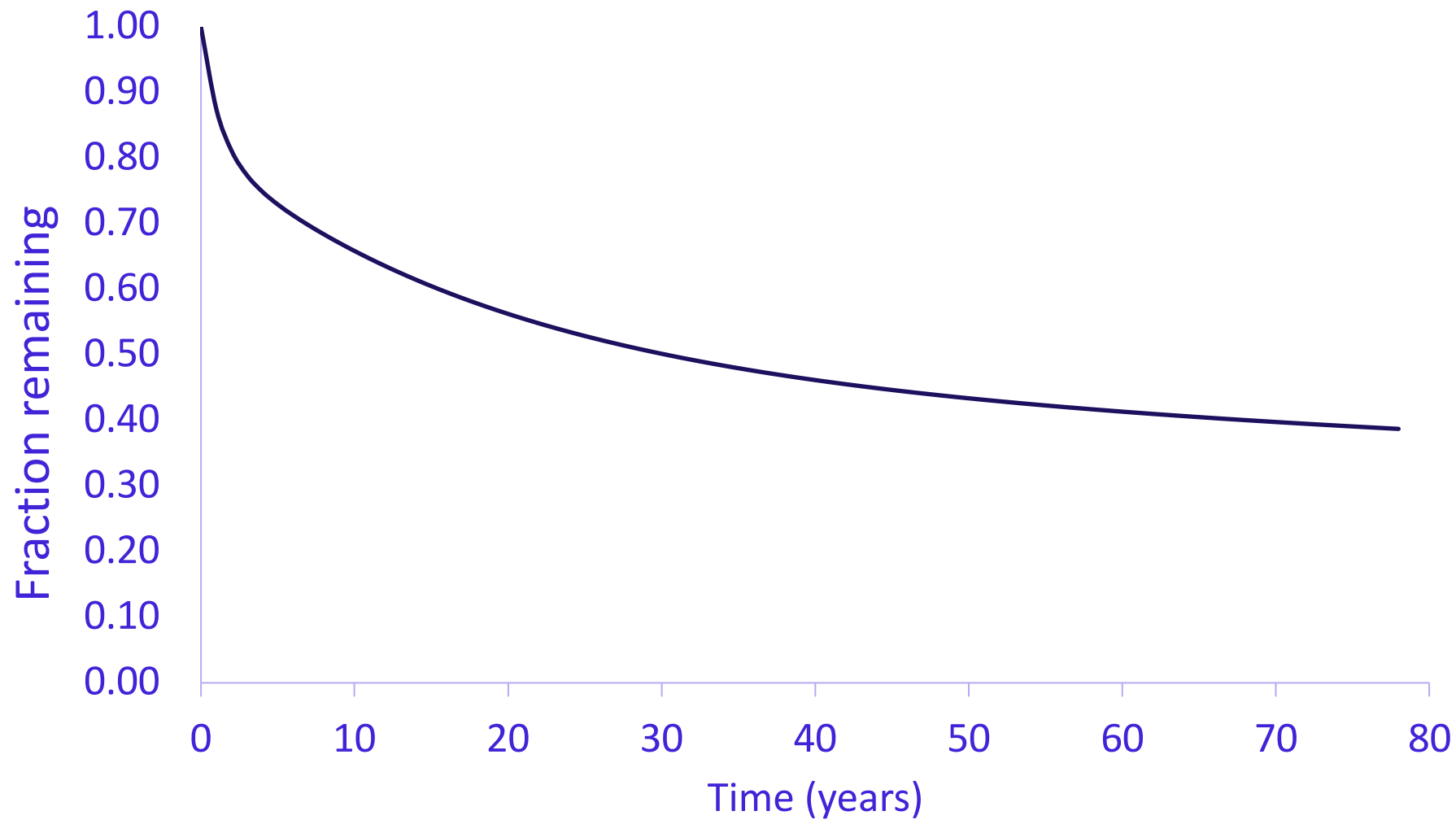
current situation - net effects



Aviation's CO₂ emissions per annum



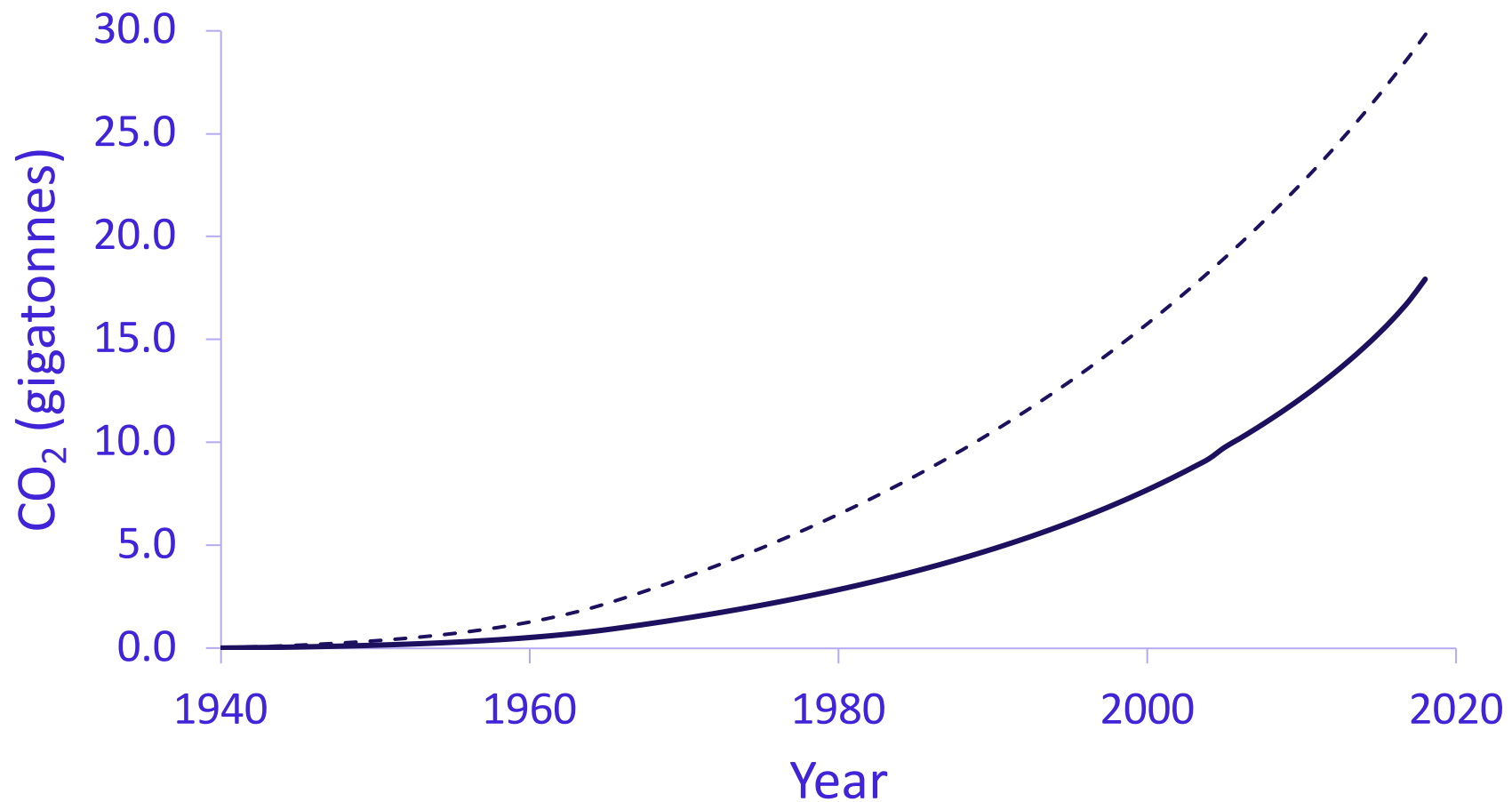
How quickly does nature remove CO₂ from the atmosphere?





- Since the natural removal processes are slow, CO₂ accumulates in the atmosphere ("half life" of a CO₂ emission is about 30 years)
- Aviation generated CO₂ in the atmosphere today is about 60% of the sum total of the CO₂ emitted by all flights since 1903.

Total aviation CO₂ in the atmosphere today



So....



- About 18 gigatonnes (1 gigatonne = 1000 million tonnes) of aviation generated CO₂ in the atmosphere today.
- Aviation is responsible for about 0.5% of all atmospheric CO₂.
- Aviation CO₂ emissions are now about 1 gigatonne per annum.
- Currently, aviation accounts for 2.5% of all annual anthropogenic CO₂ emissions, but see the more important point above.
- Operations are increasing the total aviation CO₂ by about 3.5% per annum, i.e. a doubling every 20 years, reaching 50 gigatonnes by 2050

And.....

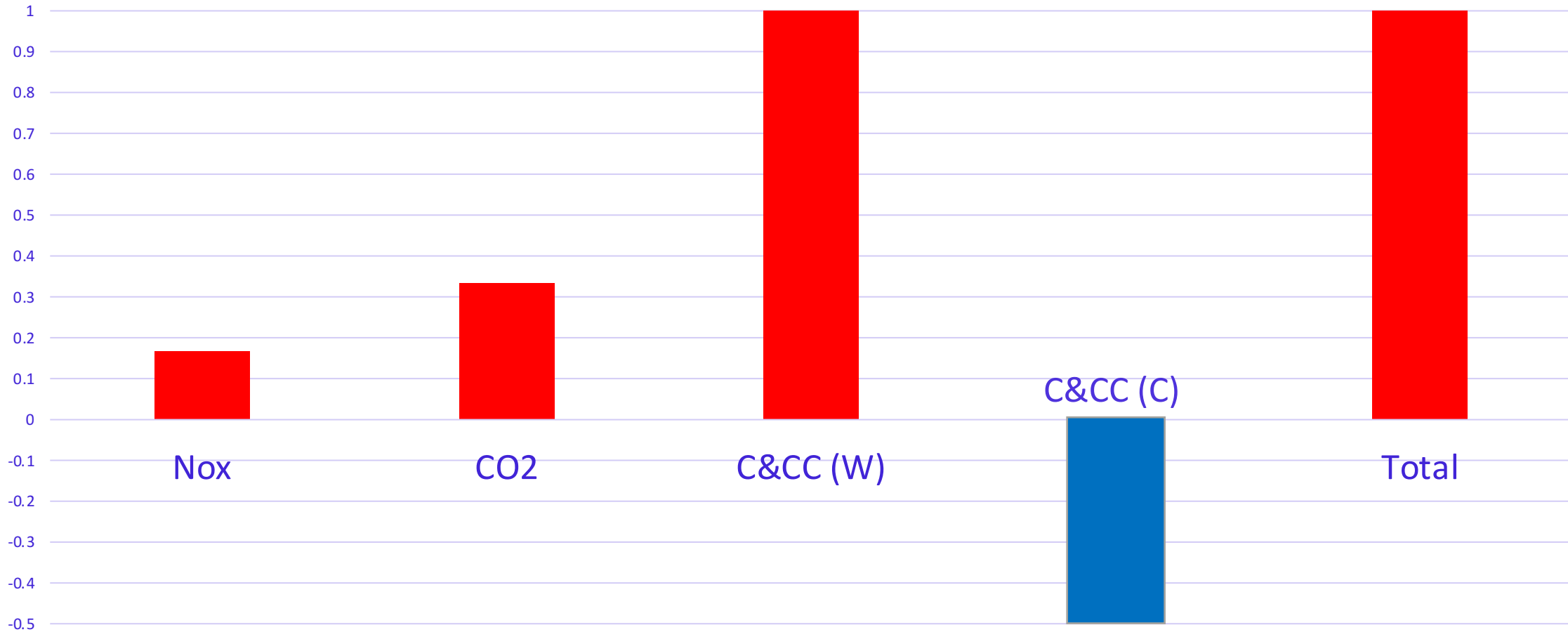


- If all aviation CO₂ emissions were stopped tomorrow, the existing 18 gigatonne pool would still be there, but decreasing to 15 gigatonnes by 2050.
- Removing carbon emissions from the aircraft has little environmental benefit “per se”.
- The “benefit” is that the problem does not get worse.
- Some might argue that, by not actually reducing environmental impact, the astronomical cost of removing CO₂ from the aircraft is a very poor return on investment.

Current situation in more detail - all effects are warming bar one



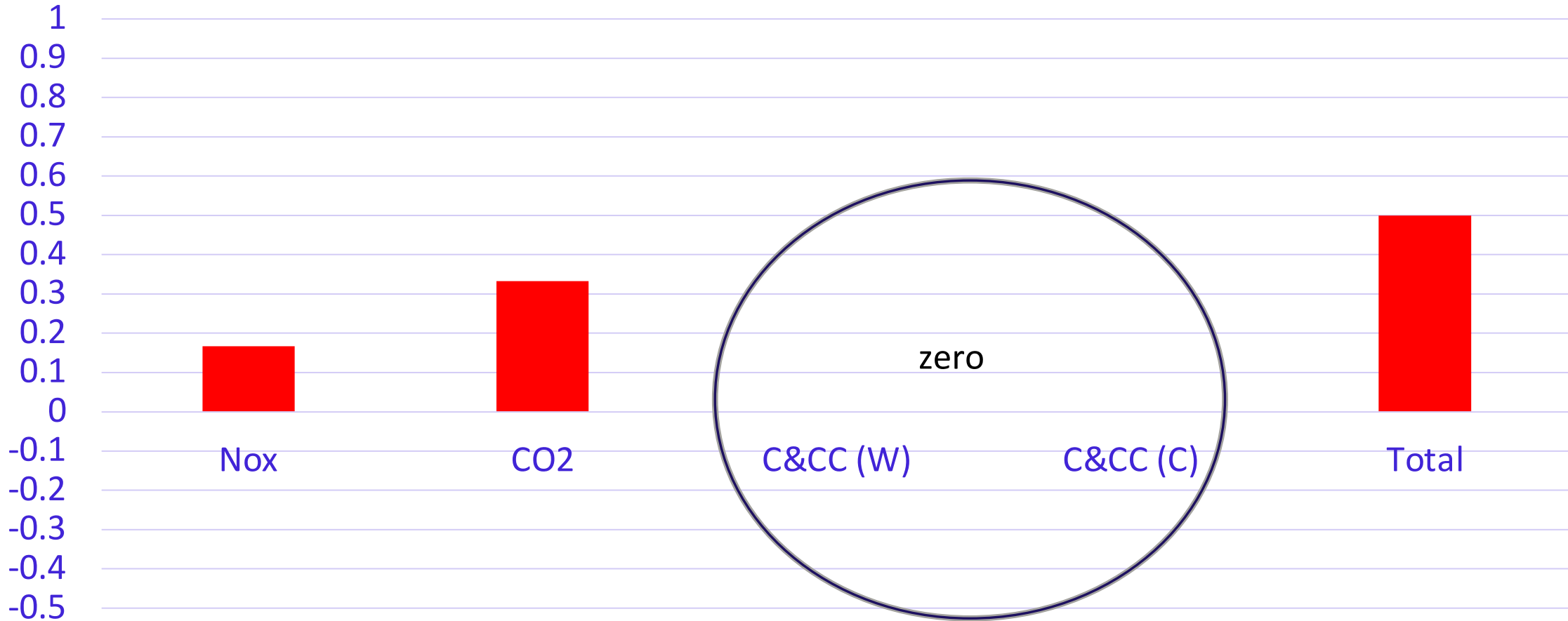
current situation - total effects



Effect of eliminating all the contrails - total is halved, but all the remaining effects are still warming



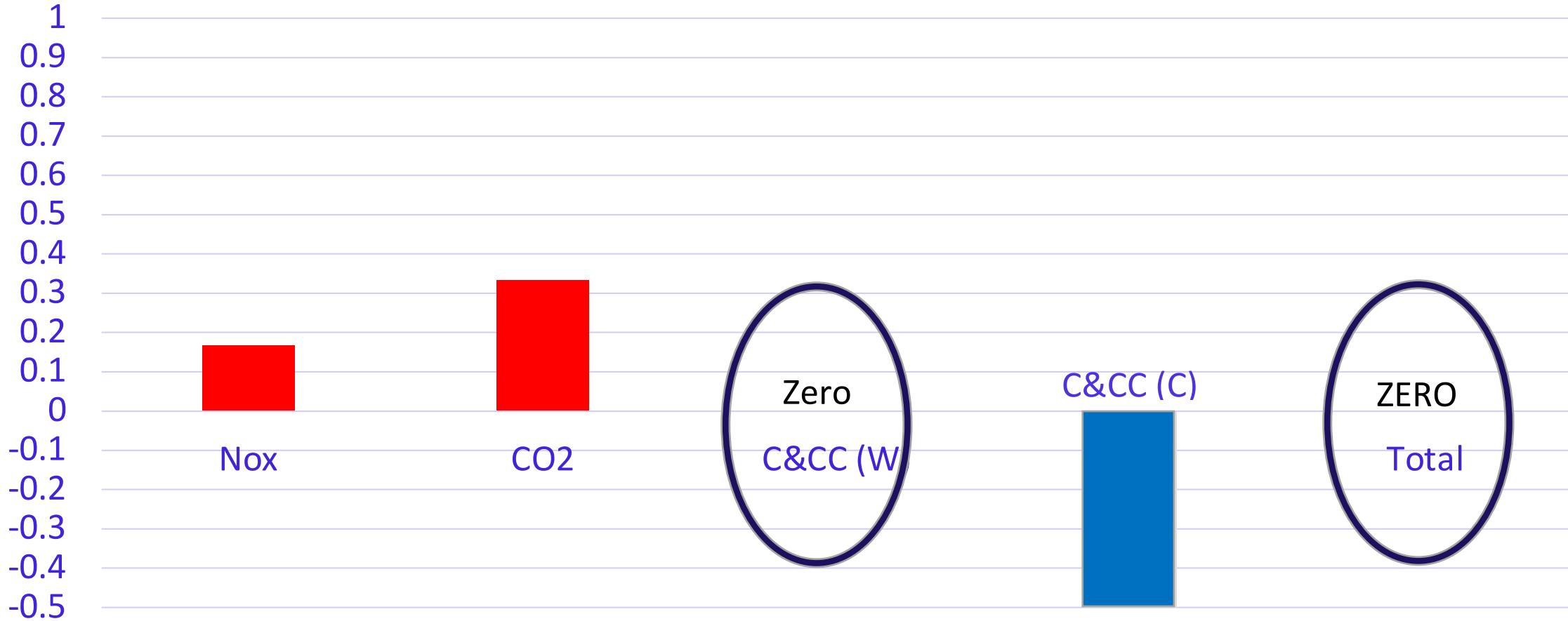
eliminate all contrails



Now just eliminate the warming contrails – net total is now zero!



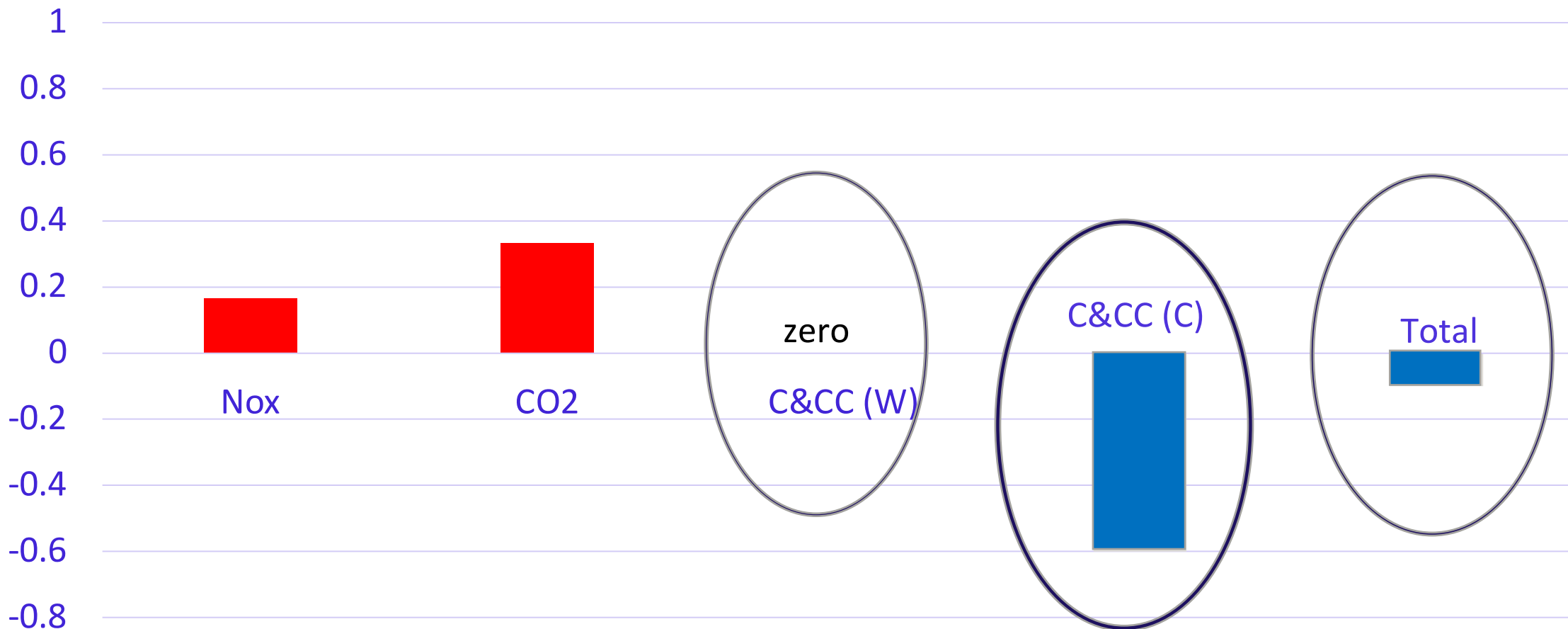
eliminate only warming contrails



...but what if we make more coolers? – net effect is cooling



eliminate warmers and make more coolers - net effect is cooling



What does this mean?



- Aviation might be able to move from being a strong warmer to either a near zero contributor or, possibly, a global cooler.
- Even the sum total of all aviation's CO₂ emissions might be offset.
- Since radiative forcing of contrails and contrail cirrus is about 1.5x aviation's current total CO₂, it is roughly equivalent to 27 (=1.5x18) gigatonnes of CO₂ annually.
- The climate impact of contrails and contrail cirrus on a per flight basis is almost 30 times that of the flight's CO₂ emission (=27/1)!!

Is this a science problem or an engineering problem



- The role of the scientist is to study phenomena and to continuously reduce uncertainty in understanding through progressive refinement, e.g. Newtonian to Einsteinian mechanics
- The role of the engineer is to achieve a practical solution to a challenge and to do this with incomplete knowledge and significant uncertainty, e.g. the steam engine and the aeroplane where the solution came before the understanding.

The environmental problem will be solved by developing engineering solutions and not by refining climate science models.



- The only problem is the operational one of making, or not making, a contrail at will.
- Contrail management is completely within the control of the industry and its service providers.
- No new technology, or outside help, is needed, not even from the airframe or engine manufacturers.
- Its initial cost is probably small enough to be absorbed into current airline budgets.

and



- It is ethical – returning the sky to pre-industrial state.
- It is effective instantly and the impact can be monitored.
- It is instantly reversible and, hence, low risk.
- It provides a mitigation against the risks of any problems with new technology, or CORSIA
- It is the only action that can reduce aviation's climate impact.
- It has the potential to change the narrative for aviation completely.



...but what are the airlines actually doing?

- Focusing on getting CO₂ off the aircraft
- Waiting for sustainable aviation fuel (SAF) in vast quantities
- Waiting for new high-tech (hydrogen) aircraft in large numbers.

But

- This partial solution horizon is decades away
- The cost is many \$trillions
- Governments must pay for most of it

In my view, this is an under mitigated and recklessly optimistic strategy that puts the whole future of commercial aviation at risk

In the meantime, GMT continues to rise!



... and what are governments doing?

- Focusing getting CO₂ off the aircraft, but not out of the environment.
- UK's Jet Zero Strategy is for zero CO₂ and not zero *GMT* impact!
- Citing scientific “uncertainty” in non-CO₂ science to delay action.
- Linking some non-CO₂ effects to (unavailable) SAF - pushing action into the future.
- At a time when many countries have the largest national debts in history and many other pressing problems, seemingly accepting that they will fund these vastly expensive rescue programs.

Is this an appropriate strategy? Is it even credible?

Contrail avoidance -“action this day”



- Contrail and contrail cirrus account for 50% of aviation’s daily *GMT* impact.
- With current operations, the contrails and the contrail cirrus are refreshed every day.
- It is within the capability of the airlines and their service providers to begin developing and implementing contrail avoidance techniques immediately.
- Initially, these could be “procedural” and require no new equipment.
- Research into the avoidance of contrails goes back 100 years.

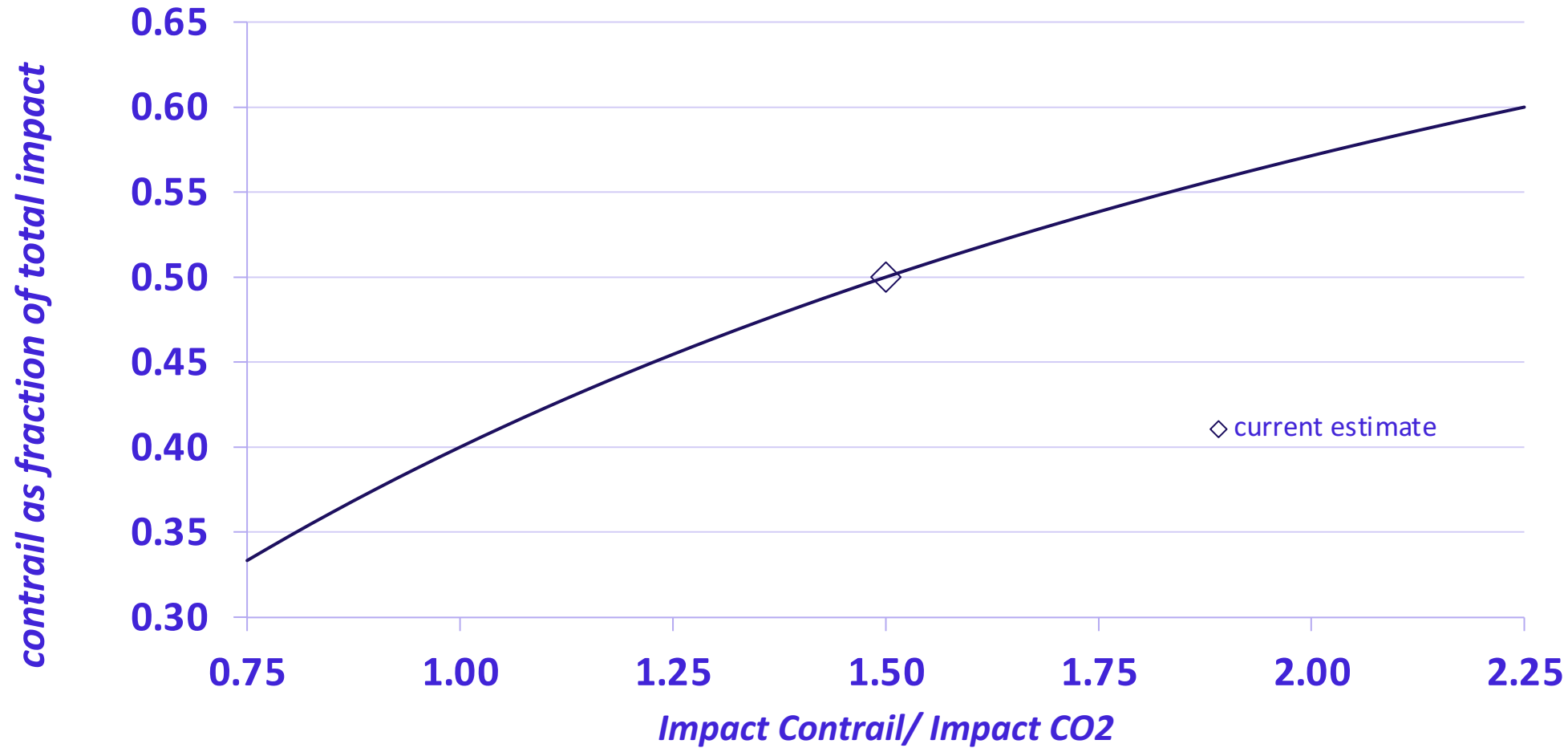
It’s simple, safe, ethical, cheap, instantly effective and available right now.

What are the arguments against immediate action?



1. The “uncertainty” in the science is too large.
2. Managing contrails will mean more CO₂

The fallacy of the scientific uncertainty excuse





...but avoiding contrails increases fuel usage, so don't do it!

- At a given aircraft weight, there is a single combination of altitude and speed at which fuel burn is an absolute minimum.
- Relative to this condition, any change in altitude, or speed, would increase the fuel burn rate – for $\pm 2000'$ or $\pm 3\%$ in Mach number, this would be about +1%.

However

- In commercial operations, aircraft rarely, if ever, fly at absolute minimum fuel burn. The actual conditions are dictated by airline economics and safety. The extra fuel is typically between 1% and 5%

Therefore, relative to the “flight plan”, changes in altitude and speed may either increase, or decrease fuel flow rate. This is a mathematical fact.

Contrail avoidance does not necessarily increase fuel burn

...just to make the key point again!



- Some contrails and their contrail cirrus warm and some cool.
- The current net effect is warming.

However,

- This is the sum of two large numbers of opposite sign (in *RF* terms magnitude of “warmers” is about twice that of “coolers”).

Therefore, if the “warmers” could be largely avoided and the “coolers” largely retained, the result would be a cooling and the net total aviation contribution would be close to zero.

This is a huge prize and immediate 100% success is not necessary.

How do you move the donkey?



1. Offer him a carrot?

- Find a way to monetise contrail management so that airlines can gain an economic benefit.
- This is not easy because only CO₂ is monetised at present

2. Give him the stick?

- Regulate to outlaw the formation of warming contrails

.....but here is why airlines should take this seriously.



- Removing CO₂ emissions does not reduce aviation's climate impact.
- If SAF, H₂ and “wonder kites” don't appear on time, CORSIA is the only backstop.
- CORSIA is riddled with problems and uncertainties, adding huge risk to airline balance sheets.
- Contrail management offers a simple, cheap, ethical way to mitigate the business risks of SAF, H₂ and CORCIA.
- Since there is no other Plan B, airlines should appreciate the business potential of contrail management for risk reduction and PR –not to mention reducing aviation's total contribution to global warming.



It's time to get serious about non-CO₂ effects

- Addressing non-CO₂ effects gives (or offers) immediate environmental benefits.
- These are very large.
- They can be delivered, initially, with existing equipment.
- They can be improved and refined at marginal cost.
- They can be delivered by the airlines themselves.
- They can be fostered, or forced, by Governments, through regulation and a little investment.

and

- They can, and should, be supported by environmental groups

Most importantly they have the potential to turn the public narrative on aviation from deeply negative to highly positive



***.....the environment is struggling and coming under
ever increasing stress.***

What are we waiting for?



.....the past 3 years have seen some significant developments

- COVID-19 provided almost clear skies for nearly two years.
- An unexpected and unprecedented opportunity to assess the true impact of aviation using hard data.

Plus

- Strong support for action on contrails from *BALPA* and similar organisations worldwide.

Some scientists, some engineers, some pilots, some environmentalists, some CEOs and some policy makers are listening. The rest need to be persuaded before it is too late.

...and finally



Thank you for your attention

Questions?

(ask me about China, Russia and India)