Managing New Zealand's greenhouse gas emissions from aviation

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Managing New Zealand's greenhouse gas emissions from aviation

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Abstract

Prior to Covid, the global aviation industry was undergoing a period of unprecedented growth and was predicted to continue growing rapidly for at least the next three decades. But the emissions growth associated with this forecast traffic growth was incompatible with the goals of the Paris Agreement on climate change. Therefore, many industry groups, governments, and NGOs have been preparing net zero 2050 pathways for aviation. One sign of this increased activity is the 'International Aviation Climate Ambition' group formed at Glasgow in 2021, whose members, including New Zealand, have committed to preparing 'ambitious and concrete' plans this year to reduce aviation emissions.

New Zealand has particularly high aviation emissions, both per capita and as a proportion of all carbon dioxide emissions, and proven ability to increase them rapidly. New Zealand has the experience of an almost complete halt to international aviation during Covid.

We survey recent developments in this area with particular reference to New Zealand, finding that aviation pathways with very high proportions of sustainable aviation fuel are unrealistic, even more so when combined with high traffic growth.

Therefore, the main other thing that affects emissions—the amount of flying, and the factors that determine it—is examined closely.

We conclude that a national action plan should include consideration of the "avoid, shift, improve" framework; emissions pricing and the "polluter pays" principle; regulation of emissions and emissions intensity; the non-CO_2 effects of aviation; the distribution of flying; the availability of substitutes, and the national strategies for those substitutes; coordination with the tourist industry; the rate of growth or degrowth; the role of airports; timely implementation; emphasis on proven technologies; the lifecycle emissions and resource requirements of sustainable aviation fuels; a fair share for aviation emissions with reference to the whole population and economy; and the transition to true sustainability respecting the rights of future generations.

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1 New Zealand's commitment within the COP26 'aviation ambition' group

On 10 November 2021 at COP26 in Glasgow, New Zealand along with twenty-two other countries joined the "International Aviation Climate Ambition Coalition", committing, amongst other things, to "Preparing up-to-date state action plans detailing ambitious and concrete national action to reduce aviation emissions and submitting these plans to ICAO well in advance of the 41st ICAO Assembly" [46]. This Assembly of the UN's International Civil Aviation Organization will take place in September 2022.

In light of this pledge, in this report we review national and global aviation emissions and examine the various measures that are in place and that have been proposed to address them. We consider the question: What would "ambitious and concrete action" to reduce aviation emissions look like for New Zealand?

On the other hand, we bear in mind that ICAO is far from the only or even the most important actor in aviation emissions. Referring to the 1997 Kyoto Protocol Article 2.2, which referred international aviation emissions to ICAO rather than the UNFCCC, Dan Rutherford of the International Council for Clean Transportation has written, "ICAO has been analyzing climate change for almost 25 years and has yet to recommend a single measure to directly reduce GHGs from planes" [73]. An ICAO spokesperson has said, "The responsibility for cutting emissions from all sectors of human activity, including but not limited to aviation, lies clearly and unambiguously with the states" [50].

Aviation is not only a large industry and a large emitter. It also underpins other sectors of the economy like tourism and trade, and it links globally dispersed families, even though an estimated 80% of the world's population have never set foot on a plane. All of these aspects are particularly acute for New Zealand, whose geography and infrastructure influence even domestic travel. If a domestic Sustainable Aviation Fuel (SAF) industry were to develop, then agriculture, land use, and renewable energy use would be implicated as well. Psychologically, the rapid rise of cheap and comfortable air travel and its continued glamorisation in the media has built support for the status quo and made addressing its emissions more difficult politically.

Climate action in New Zealand has been as slow and tortuous as in many other countries. Where there has been progress it has tended to come from adopting mechanisms tried elsewhere, such as the UK's Committee for Climate Change and the EU's Emissions Trading Scheme. Until recently, this has not been possible for aviation. But as other jurisdictions begin to refine their options, New Zealand is in a good place to start working out the most suitable way to address aviation emissions.

We close this introduction with a reminder that if there is to be limited overshoot of 1.5 °C, global net anthropogenic CO_2 emissions must decline by 45% from 2010 levels by 2030. As the chairs of the IPCC Special Report on 1.5 °C write [42],

> Without increased and urgent mitigation ambition in the coming years, leading to a sharp decline in greenhouse gas emissions by 2030, global warming will surpass 1.5 °C in the following decades, leading to irreversible loss of the most fragile ecosystems, and crisis after crisis for the most vulnerable people and societies.

We, the ministers and representatives of states, participating in the inaugural meeting of the International Aviation Climate Ambition Coalition at the 26th Conference of the Parties (COP26) to the United Nations Framework Convention on Climate Change, in Glasgow this 10 November 2021.

Being both parties to the Paris Agreement, and contracting states to the Convention on International Civil Aviation 1944 ("the Chicago Convention"). Recognising international aviation's material contribution to climate change through its CO_2 emissions, along with its additional, but less well-defined, contribution associated with non-CO_2 emissions.

Also recognising that despite the impact of COVID-19, the international aviation industry and the number of global air passengers and volume of cargo is expected to increase significantly over the next 30 years.

Acknowledging the impact of COVID-19 on the global aviation sector and the need to develop initiatives that enable the aviation industry to continue to build back better and grow in a sustainable manner.

Emphasising that international action on tackling aviation emissions is essential given the global nature of the sector and that co-operation by states and aviation stakeholders is critical for reducing the aviation sector's contribution to climate change, including its risks and impacts.

Recalling the Paris Agreement's temperature goal of holding the increase in the global average temperature to well below $2^\circ C$ above pre-industrial levels and pursuing efforts to limit the temperature increase to $1.5^\circ C$.

Recognising that achieving net zero global CO_2 emissions by 2050 will maximize the possibility of keeping the global average temperature increase below $1.5^\circ C$, and the need to align international efforts to reduce emissions from the aviation sector consistent with a pathway towards achieving this temperature limit.

Acknowledging that the International Civil Aviation Organization (ICAO) is the appropriate forum in which to address emissions from international aviation through in-sector and out-of-sector measures to implement short-, medium- and long-term goals, including the development of a global sustainability framework to support the deployment of sustainable aviation fuel (SAF) and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA).

Commit to:

1. *Working together, both through ICAO and other complementary cooperative initiatives, to advance ambitious actions to reduce aviation CO_2 emissions at a rate consistent with efforts to limit the global average temperature increase to $1.5^\circ C$.*
2. *Supporting the adoption by ICAO of an ambitious long-term aspirational goal consistent with the above-referenced temperature limit, and in view of the industry's commitments towards net zero CO_2 emissions by 2050.*
3. *Ensuring the maximum effectiveness of CORSIA, including by: supporting efforts at ICAO and working with other ICAO member states to implement and strengthen CORSIA as an important measure to address aviation emissions, including to expand participation in CORSIA, and participating in CORSIA as soon as possible, if our state has not done so already; taking steps domestically to implement Annex 16 Volume IV of the Chicago Convention as fully as possible and in a timely manner, including with respect to enforcement of domestic regulations, legislation, or Implementation arrangements; advancing the environmental ambition of the scheme in the course of undertaking the CORSIA Periodic Reviews; working to ensure that double counting is avoided through the host state's application of corresponding adjustments in accounting for its nationally determined contribution under the Paris Agreement for the mitigation underlying all CORSIA Eligible Emissions Units and, where needed, CORSIA Eligible Fuels, used toward CORSIA compliance.*
4. *Promoting the development and deployment, through international and national measures, of sustainable aviation fuels that reduce lifecycle emissions and contribute to the achievement of the UN Sustainable Development Goals (SDGs), in particular avoiding competition with food production for land use and water supply.*
5. *Promoting the development and deployment, through international and national measures, of innovative new low- and zero-carbon aircraft technologies that can reduce aviation CO_2 emissions.*
6. *Preparing up-to-date state action plans detailing ambitious and concrete national action to reduce aviation emissions and submitting these plans to ICAO well in advance of the 41st ICAO Assembly, where such plans have not already been updated in line with ICAO Assembly Resolution A40-18, paragraph 11.*
7. *Promoting capacity building support for the implementation of CORSIA and other ICAO climate measures, including to advance uptake of freely available tools and to expand regional expertise, accreditation and access to markets for sustainable aviation fuels and CORSIA Eligible Emissions Units.*
8. *Convening periodically at both ministerial and official levels with a view to advancing and reviewing progress on the above commitments. We invite other states to commit to this declaration and work with us towards our shared objectives.*

Signed by the ministers and representatives of: Burkina Faso, Canada, Costa Rica, Denmark, Finland, France, Ireland, Italy, Japan, Kenya, Republic of Korea, Maldives, Malta, Morocco, Netherlands, New Zealand, Norway, Slovenia, Spain, Sweden, Turkey, United Kingdom, United States of America.

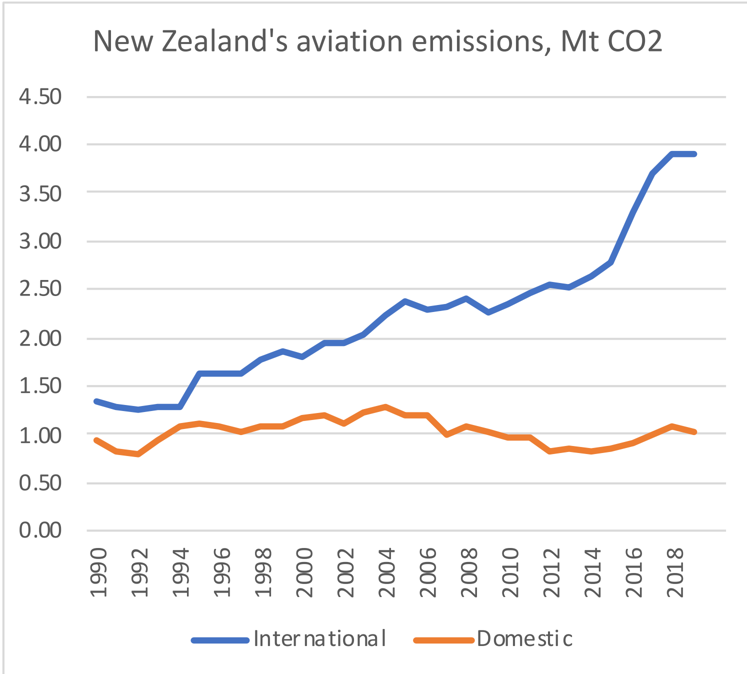

Figure 1: New Zealand aviation CO_2 emissions, 1990–2019. Source: UNFCCC [81]. Note in particular the rapid rise in emissions over the 4-year period 2015–2019, 40% for international and 20% for domestic emissions.

2 New Zealand's aviation emissions

New Zealand's aviation emissions have undergone rapid growth (see Fig. 1). International emissions tripled from 1.33 Mt CO_2 in 1990 to 3.89 Mt in 2019. Domestic emissions have fluctuated around 1 Mt CO_2. The total rise is 116%. Aviation rose from 8% to 12% of New Zealand CO_2 emissions over this period, much higher than the equivalent global proportion, which rose from 2.3% to 2.8%.

New Zealand's 2019 aviation emissions, at 4.90 Mt CO_2, can be compared to other energy-related emissions, including electricity (5.4 Mt), manufacturing (7.5 Mt), land transport (14.6 Mt), agriculture, forestry, and fishing (1.4 Mt), and buildings (1.7 Mt).

Moreover, aviation also causes climate damage through non-CO_2 effects. Their magnitude is uncertain; the current best estimate is that they are twice the CO_2 effects, making the total contribution triple [26, 48]. That puts New Zealand's 2019 aviation emissions at 15 Mt CO_2e.

New Zealand ranks 6th in the world for per-capita aviation emissions, at 1 tonne CO_2 per person, about 10 times the world average. It ranks 4th for per-capita domestic aviation emissions (Table 1) and 6th for international (Table 2).

Total international passenger movements rose from 3.5 million in 1990 to 14.2 million in 2019. This is an increase of a factor of 4, whereas emissions have multiplied by 3. Therefore emissions per passenger (taking into account aircraft efficiency, operational efficiency, and distance travelled) have declined 1% per year since 1990, similar to the global improvement

Key aspects of New Zealand's aviation emissions

- CO_2 4.9 million tonnes in 2019
- Per-capita 6th highest globally at 1 tonne CO_2 (cf. US 0.56t, EU 0.65t)
- 12% of CO_2 emissions
- Proven ability to grow emissions rapidly: International +40%, domestic +20% in 2015–2019
- International passengers fell 97.6% in the 12 months to March 2021
- Domestic aviation CO_2 included in NZ ETS and the falling cap on emissions
- Founding member of the International Aviation Climate Ambition Coalition, committed to presenting an "ambitious and concrete national action plan" in 2022 to reduce aviation emissions

Table 1: The top 10 countries for per-capita domestic aviation CO_2 emissions [67]. The US, Australia, and Canada are all very large countries. Norway and New Zealand are the outliers here.

United States	386 kg
Australia	267 kg
Norway	209 kg
New Zealand	174 kg
Canada	168 kg
Japan	74 kg
Iceland	71 kg
Chile	70 kg
France	70 kg
Saudi Arabia	65 kg

Table 2: The top 10 countries for per-capita international aviation CO_2 emissions [67]. Middle: direct emissions. Note that Qatar, UAE, and Singapore are transit hubs, while Iceland and Malta have large tourism industries, with 6 (resp. 4) international visitors per capita, cf. New Zealand 0.8. Right: emissions of complete journeys starting or ending in the country (e.g. NZ–UK) [29]. Small island states dominate by this latter measure (such as the Cook Islands, 3000 kg/person).

	direct	indirect
Iceland	3506 kg	2626 kg
Qatar	2473 kg	515 kg
UAE	2195 kg	816 kg
Singapore	1741 kg	1047 kg
Malta	992 kg	1261 kg
New Zealand	640 kg	760 kg
Mauritius	600 kg	650 kg
Ireland	574 kg	627 kg
Switzerland	513 kg	548 kg
Australia	496 kg	711 kg

observed over 1960–2014 of 1.3% per year [35] but less than the 56% improvement globally over the period [52]. One factor could be an increase in the average distance of flights, which we do not know.

The factors behind this growth are many, but two key ones are price and quality. Since Air New Zealand launched their Auckland–London flight in August 1982, prices have fallen 70% in real terms, while incomes have risen. Real GDP per person has risen 75% since 1982, so that prices relative to income have fallen by a factor of 6 [21]. The same is true for trans-Tasman flights. In addition, long-haul flights have become steadily more reliable and comfortable over the decades.

More passengers means more flights. The Tourism Satellite Account [76] lists more than 100 new and expanded routes during the 2016–2019 period of very rapid growth, some of them extremely long, such as Auckland to Buenos Aires, Chengdu, Chicago, Doha, Dubai, and Ho Chi Minh City.

For New Zealanders returning from overseas, 15% had been travelling for business or education, 42% for holidays, and 36% to visit friends and family. (These travellers could be resident either in New Zealand or overseas.) Of non-New Zealand travellers, 12% were travelling for business or education, 52% for holidays, and 28% to visit friends and family [76].

In 1996, 17.5% of the New Zealand population were born overseas. In 2001, 19.5%; in 2006, 22.9%; in 2013, 25.2%, and in 2018, 27.4%. The two largest groups of migrants are from the UK (265,000 people) and China (144,000). Perhaps 1 million New Zealanders live overseas, including one in six Māori [71].

We do not have complete data on domestic passenger numbers. However, Auckland Airport domestic passengers grew from 3.2 million in 2000 [2] to 9.1 million in 2017–18 [56], 34% of New Zealand's total—6.4% annual growth. As emissions only rose by a quarter, this suggests efficiency improvements of 56%, more than 5% per year. For example, Boeing 737s were replaced by Airbus A320s, which use 35% less fuel. However, a recent emissions increase of 25% in the past five years suggests that either this progress has either come to an end or we are at a trough in the improvement cycle.

The Ministry of Transport lists 29 airlines that operated in New Zealand prior to Covid [60], 12 of them having started New Zealand operations in the past decade.

Aviation in New Zealand is governed by the Civil Aviation Act 1990 and the Airport Authorities 1966. A new Civil Aviation Bill before parliament in 2022 will replace both of these. For the first time, it mentions greenhouse gas emissions, containing provisions to enable the operation of the ICAO's CORSIA carbon offsetting scheme. Most of the Bill (and the Civil Aviation Authority's operations) are concerned with safety and security.

Emissions from domestic aviation are included in the New Zealand Emissions Trading Scheme (ETS) since the scheme's inception in 2010. GST is charged on most domestic flights. There is no fuel excise tax. There are some fees, such as a $1.60 fee per passenger CAA fee. At an ETS price of $77/tCO_2$, a return flight from Auckland to Christchurch (0.194 tCO_2) the ETS charge is $14.90, out of a ticket price which can range from $118 to $920. Some airlines also offer optional carbon offsetting schemes. For example, Air New Zealand offers offsetting at $24/tCO_2$, or $4.68 for Auckland–Christchurch return.[1]

Emissions from international aviation are not included in the ETS. GST is not charged on international flights, or on domestic flights which connect to international flights. There is no fuel excise tax. There is an airport and security fee of $50 per ticket.

The customer loyalty schemes *Flybuys* and Air New Zealand's *Airpoints* have grown rapidly, with 2.4 million and 3 million members respectively.

3 The Paris Agreement and the Zero Carbon Act

The 2016 Paris Agreement does not mention aviation specifically. (The only sector that is mentioned individually is agriculture.) Nevertheless, the agreement to limit warming to "to well below 2.0 °C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5 °C above preindustrial levels" and to reach net zero emissions globally in the second half of this century, does include all sectors, including international aviation and shipping, as does the agreement for developed countries to undertake "economy-wide" emission reductions.

At present, emissions from international shipping and aviation are not included in national emissions, although they are reported to the UNFCCC for noting. So far, no country or jurisdiction has included these emissions in their Paris Agreement pledges (NDCs).[2]

New Zealand's Climate Change Response (Zero Carbon) Amendment Act 2019, informally known as the Zero Carbon Act, has adopted the 1.5 °C target, interpreted as reaching net zero emissions of long-lived gases (mostly CO_2) by and beyond 2050, along with substantial cuts in short-lived gases (mostly methane). International aviation is not presently included either in the targets or the carbon budgets. The Climate Change Commission has been asked to advise by 2024 on whether international aviation and shipping should be

[1] All dollars are nominal New Zealand dollars unless otherwise stated.

[2] The United Kingdom included emissions from international aviation and shipping in its sixth carbon budget for the period 2033-2037, and stated that these emissions are included in the net zero target for 2050.

included in the 2050 target. The first three carbon budgets and the CCC's demonstration pathway to 2050 include room to include these sectors in the net zero 2050 targets.

However, questions have been raised as to whether the targets themselves are strict enough and whether they are compatible with the 1.5 °C goal, which requires net zero long-lived gases for the whole world by 2050, and earlier for the developed countries (as per the Paris Agreement). Christina Hood, former head of the IEA climate change unit, has argued that they should be strengthened immediately, as the 2050 target will influence policies in the 2020s [40]. The question will also be addressed by the courts: in July 2021 Lawyers for Climate Action New Zealand filed for a judicial review of the Climate Change Commission's advice, stating that the proposed emissions budgets are "irrational, unreasonable, and inconsistent with the purpose of the [Zero Carbon] Act" [51].

Policies to address aviation emissions are in preparation in the UK ("Jet Zero"), EU ("Fit for 55"), and US (through the EPA, and mentioned in Presidential Executive Orders of 20 and 27 January 2021).

In summary, many factors—the urgent need to phase out the burning of fossil fuels, New Zealand legislation, the Government's climate goals, international agreements, and emerging international action—point towards reducing aviation emissions. New Zealand's distinctive situation and the novelty of the challenge indicate that all possible solutions should be examined carefully.

4 New technology

4.1 Incremental improvements

Past improvements in efficiency (emissions per passenger–kilometre) have come from more efficient planes and operations. Aircraft improvements include aerodynamics (e.g. wingtips), weight (especially the recent shift from aluminium to carbon fibre) and engines, and also larger planes and longer flights. Operational improvements include higher occupancy and less time waiting to land.

The aircraft industry anticipates continued improvements in all of these things. However, each is subject to a fundamental limit. In addition, the planes now in operation and on order will be in operation for many decades, during which time emissions must be reduced.

Space per passenger is a major component of efficiency, but this has tended to move in both directions, with budget airlines decreasing space and full service airlines increasing it by allocating more space to business and first class passengers. The A380 was designed to carry 853 passengers, but this never happened; it has been used to seat just 379.

Longer flights are in general more efficient per kilometre, although there has been a recent trend for ultra-long flights, which reverses this. Long flights also increase comfort and convenience (fewer stops), which act to increase total travel.

4.2 "Zero-emission" aircraft

A great deal of media attention has been focused on projects and proposals for zero-emission aircraft, of which the three main contenders are battery electric, hydrogen electric, and hydrogen combustion. (Emissions would be very low or zero during flight; lifecycle emissions including building the aircraft and making the fuel and providing renewable energy for it would not of course be zero.) Numerous small electric aircraft under development, some aiming at commercial use in the mid-2020s, and Airbus are aiming for hydrogen-powered flight by 2035.

As no such commercial aircraft exist at present, the uncertainties are large. The engineering challenges for usable performance even from small electric aircraft are substantial, although the short-hop 19-seater that Sounds Air hope to operate by 2026 may be feasible [14]. Zero-emission aircraft do not enjoy the energy efficiency gains of electric or hydrogen land transport, because the batteries or tanks have to be lifted. A schematic hydrogen aircraft [61] is actually *less* energy-efficient than a standard aircraft, due to its very large, heavy tanks.

If these aircraft do become a reality, they would need to be supplied with electricity or hydrogen. The energy required is significant. Mason *et al.* [53] find that under business-as-usual growth in aviation, 42 TWh of electricity would be needed by 2050—equal to New Zealand's entire current supply, and dwarfing the 7 TWh of fossil fuel-fired electricity which the government is currently hoping to phase out. In addition, New Zealand would be attempting to replace all the fossil fuels used in land transport, and a lot of those used in industry, with electricity and/or hydrogen at the same time. Electrolysers tend to be placed where the fuel is needed, indicating a need for a 3800 MW electrolyser at Auckland airport, a power demand equivalent to about 6 times that produced by the Manapouri power station. (About 200 MW of electrolysis is currently in existence worldwide.) Power could be provided, for example, by 14,000 MW of wind turbines, i.e., 63 copies of the Turitea wind farm that is currently under construction at a cost of $370 million. The resulting substantial increase in intermittent supply in the electricity grid would mean that more storage or oversized electrolysers would also be needed.

In other words, the energy requirements are extreme.

Despite this, new developments or announcements are greeted with excitement. On 1 November 2021, the first electric plane to cross Cook Strait—a 2-seater Pipistrel Alpha Electro—arrived in Wellington [34]:

> Climate Change Minister James Shaw, speaking to the group of public officials and aviation industry professionals gathered in the terminal to celebrate the plane's arrival, said it was entirely possible the aviation industry could decarbonise faster than the transport industry. "There's only about four purchasing managers in the entire country who will have to make a different decision once the technology becomes available to them. We've always needed aviation, particularly when it comes to our regional access, and electric aviation opens up a lot of these small remote places, because obviously electricity is so much cheaper than aviation fuel."

4.3 Sustainable Aviation Fuels

> Sustainable aviation fuel (SAF) is the main term used by the aviation industry to describe a nonconventional (fossil derived) aviation fuel. SAF is the preferred IATA term for this type of fuel although when other terms such as sustainable

> alternative fuel, sustainable alternative jet fuel, renewable jet fuel or biojet fuel are used, in general, the same intent is meant. 'Biofuels' typically refers to fuels produced from biological resources (plant or animal material). However, current technology allows fuel to be produced from other alternative sources, including non-biological resources; thus, the term is adjusted to highlight the sustainable nature of these fuels. The chemical and physical characteristics of SAF are almost identical to those of conventional jet fuel and they can be safely mixed with the latter to varying degrees, use the same supply infrastructure and do not require the adaptation of aircraft or engines. Fuels with these properties are called "drop-in fuels" (i.e. fuels that can be automatically incorporated into existing airport fuelling systems). Moreover, to validly use the term "sustainable" they must meet sustainability criteria such as lifecycle carbon emissions reduction, limited fresh-water requirements, no competition with needed food production (like first generation biofuels) and no deforestation. IATA [44]

The lion's share of many aviation pathways focus on sustainable aviation fuels (SAF); see Rae and Callister [71] for a New Zealand-oriented review. The challenges of these pathways are extreme. In 2019, 0.05% of global aviation fuel was biofuel, made from food crops and waste food such as tallow and used cooking oil. These are limited in supply, as is household organic waste (a feedstock presently under commercial development in the US). Therefore, pathways with high levels of SAF look to other feedstocks, especially (for New Zealand) wood waste and logs. However, there are no such plants in commercial operation. A report from the ICCT [66] concluded that the EU could be capable of producing 2 Mt a year of wood-based biofuel by 2035, about a quarter of the proposed mandate in "Fit for 55" and slightly more than New Zealand's 2019 consumption of jet fuel. Closing the apparent gap—a factor of 100—will need close attention.

Biofuels can vary considerably in their lifecycle emission reductions, which can be very hard to estimate accurately [69]. To consider an artificial example, in a net zero scenario with a 100% SAF mandate and fuels which reduce lifecycle emissions by 50%, the net reduction in emissions would be only 50%. So even a 100% SAF mandate may require significant offsetting.

New Zealand is in the process of implementing a biofuel mandate for land transport, with a target of 9% lifecycle GHG reduction from biofuel by 2035. (This would be met initially from imports, with allowable feedstocks yet to be determined.) Longer-term, the options for domestic biofuel production from waste wood (which have good lifecycle GHG reductions of 80–90%) are being explored. An initial study estimates that a $520 million plant could produce 57 million litres of fuel per year, 0.7% of New Zealand's liquid fuel consumption, and that there is enough feedstock available for 20 such plants [9]. To avoid transport costs and emissions, the plants must be located near the forests. A wood-to-fuel plant is presently under construction in the US by Lanzatech.

E-fuels, made directly from water and carbon dioxide (sourced from the air or from flue gases) and a lot of renewable electricity, can potentially be supplied in any amount. They also eliminate some of the environmental effects of biofuels and some of the non-CO_2 effects of burning fossil fuels in aircraft. A number of small trial plants are under construction in Europe. The obstacles are cost and (if the industry were to scale up) renewable electricity supply. The ICCT estimate [66] that at €2/L support, the EU could produce 0.23 Mt a year of e-fuels by 2035, one tenth of the proposed mandate under "Fit for 55." If this cost (5 times the current price of jet fuel, and equivalent to a carbon price of €800/tCO_2) were added to ticket prices, they would triple. This, however, should be seen as a positive combination: e-fuels are better in some ways than a straight tax. They increase the price of travel while also reducing emissions at the source. The energy requirements are about twice that of hydrogen electrolysis.

An ambitious scenario for 2035 for aviation SAF for New Zealand would involve two $520m wood-based biofuel plants (producing 57 million litres a year each) and one 100 MW e-fuel plant producing 40 million litres a year. Together they would provide 8% of New Zealand's aviation fuel at 2019 levels of demand. It should be considered whether this could be achieved simultaneously with a rapid expansion of green hydrogen and low-carbon biofuel for non-aviation applications. In addition, if demand were to grow as envisaged by existing airport expansion plans, total emissions would grow while the difficulty and cost of meeting such a proportion of SAF would increase.

Overall, although New Zealand has comparatively superior potential resources of both renewable electricity and of feedstock for advanced biofuels, significant capital investment and advance planning would be required to exploit them. Nevertheless, sustainable aviation fuel mandates open up synergistic pathways in which the higher costs of sustainable fuels lead to greater focus on efficiency and lower traffic growth.

4.4 Conclusion

The obstacles in the way of a technological solution to aviation emissions are formidable. In addition to cost, technological readiness, feedstock supply, and environmental side-effects, there are difficult timing issues. On one hand, emission reductions are needed now, but the alternatives are not ready; on the other, it is hard to reliably forecast the future cost of different solutions in order to make the necessary decisions now. All of this is seemingly at odds with institutional pathways' reliance on technological solutions and their media coverage.

A comprehensive study by Grewe *al.* [35] considered a wide range of scenarios for growth, technology, and Covid response, finding that only the most optimistic scenarios involving rapid uptake of new technology could stabilise aviation's climate impact in the second half of the century, but that a technology assessment expert group found these scenarios implausible.

New technology plays a complex role in climate change with, by now, a long history. McLaren and Markusson [54] discuss 'technologies of prevarication', outlining a cycle in which technological promises have "enabled a continued politics of prevarication and inadequate action by raising expectations of more effective policy options becoming available in the future, in turn justifying existing limited and gradualist policy choices and thus diminishing the perceived urgency of deploying costly and unpopular, but better understood and tested, options for policy in the short term." Examples include forestry, nuclear power, energy efficiency, CCS, BECCS, direct air capture of CO_2, and solar radiation management. Meanwhile, even the simplest promises such as energy efficiency have failed to be adopted quickly and widely enough.

5 Stronger pathways

The 2019 study *Absolute Zero* from the UK FIRES consortium [5] is based on the premise that radically new technologies—like hydrogen planes, e-fuels, and bio-energy with carbon capture and storage—will not be able to scale up rapidly to make a difference within 30 years. Therefore, virtually all sources of emissions have to be phased out using today's technologies. In fact, they regard talk of new technologies as actively damaging: "It's difficult to start discussing how we really want to address climate change while we keep hoping that new technologies will take the problem away."

For aviation, the report concludes that as there are no options for zero-emissions flight in the time available, the industry faces a rapid contraction. The Absolute Zero pathway involves all UK airports except Heathrow, Glasgow, and Belfast closing in the 2020s, and these three phasing out conventional flight by 2050. Electric flight and e-fuels may allow flight to resume when sufficient zero carbon electricity is available.

Klöwer *et al.* [48] describe an apparently less disruptive pathway with even better environmental impact. The key (or catch) is that they include the non-CO_2 effects of aviation. They find that if aviation were to decline at 2.5%/year, *or* there were a transition to a 90% carbon-neutral fuel mix by 2050, then "the impacts of the continued rise in accumulated CO_2 emissions and the fall of non-CO_2 climate forcers would balance each other, leading to no further increase in aviation-induced warming with immediate effect." That is, net zero would be reached almost immediately. The catch is that developing such a strategy involves recognising and controlling the non-CO_2 effects of aviation, which are currently unregulated and are twice as large as the CO_2 effects.

6 The industry view

The International Air Transport Association, a trade association of the world's airlines, initially established a goal of halving net emissions between 2010 and 2050. In 2021, this was strengthened to net zero by 2050. The IATA plan forecasts passenger numbers to grow from 4.5 billion in 2019 to 10 billion in 2050, with net zero emissions to be achieved by 65% SAF, 13% new technology such as hydrogen aircraft, 3% operations, 11% CCS, and 8% offsetting. SAF use in the aviation industry would grow from 0.2 Mt in 2019 to 18 Mt in 2030 and 180 Mt in 2040, while it is claimed that the industry is not reliant on zero-emission aircraft to meet net-zero [83].

The actual resolution agreed by members, however, is considerably less specific [43]. It does not contain these targets or mechanisms by which they would be met; the agreement covers general aspirations and calls for government support. In particular, governments are asked that their aviation plans do not rely on ticket or carbon taxes.

Industry-led forecasts of rapid passenger growth (+120% by 2050, or 3% per year) require continuously accelerating behaviour change from the public, who would be spending more and more of their time flying under such scenarios.

Air New Zealand has taken an increasingly strong line on sustainability, which has been maintained and even strengthened during Covid. Their 2021 sustainability report [3] was the first to outline a schematic pathway to reach net zero by 2050. It involves about 75% passenger growth by 2050, with net zero to be achieved by 20% of the emissions cuts coming from new conventional aircraft; 20% from zero-emission aircraft; 50% from SAF (implying an 86% SAF mandate); 2% from operations; and 8% from offsetting.

They see a need for strong government action to establish a domestic SAF industry, first based on forestry residues with a domestic plant running by 2027, then on waste, then (from 2045) on whole logs and e-fuels, with steady progress ensured via an SAF mandate [4]. The head of Air New Zealand's sustainability advisory panel, Jonathan Porritt, commented that

> New Zealand will always be a price-taker. By 2030, it will be the big players in the industry who will be determining that price. The only way of managing that risk is for New Zealand to ensure its own, indigenous SAF capability—and that means taking big decisions in a clear and accountable way over the next couple of years.

The Ministry of Business, Innovation, and Employment will advise on an aviation SAF mandate in 2022, with the mandate proposed to start in 2025.

7 Offsetting

Prior to 2020, the main climate strategy put forward by the aviation industry was offsetting. This formed the basis of ICAO's CORSIA scheme, originally intended to cap net emissions at 2020 levels. When Covid led to a fall in traffic in 2020, the baseline was reset to 2019, so CORSIA is unlikely to do anything at all for several years. A study for the European Commission found that none of the offsetting programmes approved under CORSIA met all of the quality requirements; that all of them had issues with double counting—for example, claiming credit for emission reductions already covered by national climate targets; that the price of offsets (less than €1) provides no incentive to reduce emissions; and that secrecy at ICAO prevents independent verification of the scheme's operation [24].

Voluntary offsetting is also possible. At Air New Zealand this operates under the Fly-Neutral programme, which offsets 7% of emissions. The current price is around $\$24/tCO_2$, of which \$6 is used to offset emissions in international projects arranged through the company ClimateCare, and the rest is directed to New Zealand biodiversity projects through organisations such as Trees That Count and the Native Forest Restoration Trust.

The entire topic of offsetting and its role in climate solutions is controversial. For example, Carton *et al.* [19] discuss putative carbon, geographical, and temporal equivalences between positive and negative emissions, and conclude that climate justice requires their uncoupling:

> Increasing carbon in terrestrial sinks simply replaces carbon that has been lost to the atmosphere over past centuries. Fossil carbon, on the other hand, is permanently locked away. Thus, burning fossil fuels moves carbon from permanent storage into the active carbon cycle, causing an aggregate increase in land, ocean, and atmospheric carbon. Once added, this additional carbon cannot be removed through natural sinks on time-scales relevant to climate mitigation.

In addition, on purely physical grounds, Zickfeld *et al.* [85] conclude that a CO_2 emission into the atmosphere is more effective at raising atmospheric CO_2 than an equivalent CO_2 removal is at lowering it.

For these and other reasons, the NGO Climate Action Tracker recognises gross emissions only.

The issue is particularly acute for New Zealand, where mitigation pathways require forestry to rapidly and continuously increase to 2050 and beyond. Emissions from the first half of the century would be stored above ground and maintained by our descendants in the second half of the century. In addition, current proposals are for two-thirds of New Zealand's Paris Agreement target for 2030 to be achieved internationally—much of which could again be by offsets. In other words, the availability of offsets has in part determined a pathway which involves higher fossil fuel use than would otherwise be the case.

Even if offsetting programs could satisfy all requirements for integrity, they could still act so as to deter gross emission reductions. People might fly (believing it to have no climate impact), and airlines might increase gross emissions (having escaped national regulation). Certainly offsetting has been a mechanism for ICAO to avoid having to develop standards that reduce emissions at the source.

Therefore, the renewed emphasis since 2020 on true net zero pathways for aviation that involve only small amounts of offsetting is welcome. Whether offsetting has any useful role to play in the next few decades, though, is an open question.

8 EU Fit for 55 & UK Jet Zero

Two principal jurisdictions that have begun efforts to address aviation emissions are the EU and the UK. This work is not new, as intra-EU aviation has been partly covered by the EU ETS since its inception. The EU was sceptical of the CORSIA scheme and had always intended to review its performance and their regulation of extra-EU aviation. But the EU's new NDC under the Paris Agreement, to cut emissions to 55% below 1990 levels by 2030, via the "Fit for 55" program, has hastened this work. Meanwhile, the UK has included international aviation in its 6th carbon budget for 2033–2037, leading to their "Jet Zero" plan. Neither plan has yet been adopted.

Under "Fit for 55", the EU will phase out free ETS allowances for intra-EU aviation (currently covering about half of such travel) over 2024–2027, and reduce the emissions cap of the whole ETS faster. They will tax jet fuel for intra-EU flights from 2023, with the tax rising linearly to €0.38/L (equivalent to €154/tCO_2) by 2033. For all flights, an SAF mandate would rise from 5% in 2030 to 20% in 2035 and 63% by 2050, for which only waste wood and fats and e-fuels would qualify. Taxation for extra-EU flights would be left up to each country to determine, while CORSIA would remain in place.

The EU has also explored options for addressing the non-CO_2 impacts of aviation [26].

Their model forecasts a baseline growth in emissions of 20% over 2015–2050, with the new proposals reducing emissions by 60% for an overall reduction of 52%.

The NGO *Transport and Environment* said the EU should reject CORSIA ("a cheap offsetting scheme that continues to allow aviation emissions to grow. It includes credits that don't actually deliver emissions reductions, risk being double counted and are mostly priced under €1") and instead apply the ETS to all flights [23]. They also recommended applying a multiplier for non-CO_2 effects and dedicating ETS revenues to e-fuel production.

The UK's *Jet Zero* has a headline goal of net zero aviation by 2050. It sees aviation emissions rising from 37 $MtCO_2$ in 2019 to 39 Mt in 2030, then falling to 31 Mt in 2004 and 21 Mt in 2050—a 42% reduction from 2019, but a 63% reduction from their baseline which includes traffic growth of 54%. Reductions are to be comprised of demand reductions 8.8%; efficiency gains 36%; zero emission aircraft 4.1%; SAF 14.4%; and offsets 36.7%.

SAF proposals are oriented around the establishment of a very large domestic industry, with 25–125 large SAF plants in the UK by 2050. The draft includes a very wide range of possible pathways. Other components are to retain the ETS for UK–EU flights, to 'strengthen carbon pricing', and to require zero emission domestic aviation by 2040.

Jet Zero includes a comment that "any growth in aviation must be compatible with our emissions reduction commitments"—although they allow more growth than the 25% included in the UK CCC balanced net zero pathway, discussed below.

Although it represented something of a landmark initiative, *Jet Zero* was poorly received by environmental groups.

The ICCT remarked that none of the six pathways were consistent with the Paris Agreement, as they would lead to aviation using up its share of the remaining carbon budget for 1.7 °C by the late 2030s [72].

The Aviation Environment Foundation said that the proposals would not achieve the pathways: they include too much growth, do not take into account the true emissions of SAF or its cost, were too optimistic about new technologies, and do not put in place clear price signals [25]. They recommended adopting the 'polluter pays' principle that the industry should pay the costs of its own decarbonisation. In addition, the government should regulate frequent flyer programmes and not support airport expansion as a "means of managing supply that will prepare the industry for the lower levels that can be expected once carbon pricing is meaningfully introduced."

Transport and Environment described the proposals as "all carrot, no stick" [27]. In their view Jet Zero has no requirement for zero emission planes; nothing to curb demand; nothing for the near term; assumes that the government has plentiful carbon removal options in place for 2050, which should be the industry's job; does not ensure that 2019's emission levels are never reached again, should set conditions that ensure that private capital delivers SAF and zero emission aircraft; should not use the term "high ambition" to describe 21 Mt CO_2 emissions in 2050, true "high ambition" would be zero emissions; should include a separate e-fuel mandate (as the EU is proposing) as waste feedstocks are limited; and non-CO_2 effects should be included in the ETS immediately until airlines can find a better way.

The UK Committee for Climate Change is responsible for a broad range of advice to and oversight of the government, in particular related to carbon budgets. The UK's 6th carbon budget (2033-37) includes international aviation and shipping. Therefore, their pathways to Net Zero 2050 have been revised to reflect this. UK aviation emissions were 39.3 Mt CO_2 in 2018, or 0.59 tCO_2 per person (cf. New Zealand 1 tCO_2 per person). These comprised 7% of total UK GHG emissions. Of this, just 7% were domestic.

The UK CCC's 'Balanced Net Zero' pathway foresees passenger growth of 25% by 2050 (compared to 64% in the baseline model) and no increased airport capacity. Efficiency

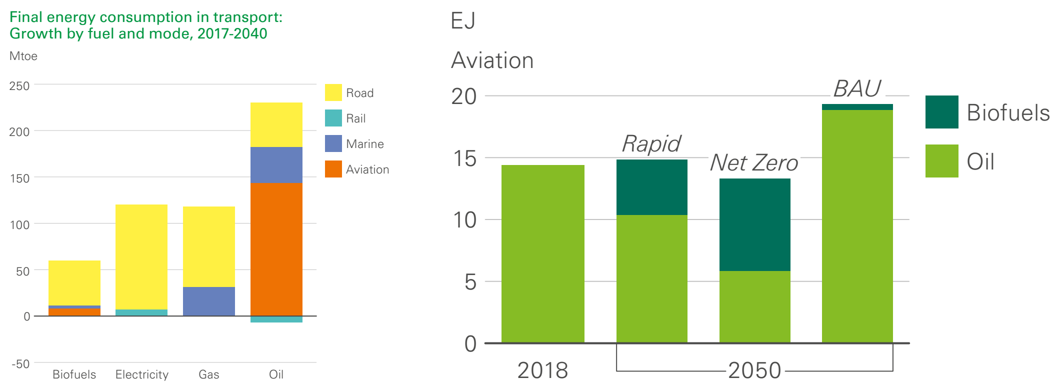

Figure 2: The oil industry's reliance on aviation growth. Scenarios from the *BP Energy Outlook* for 2019 (left) and 2020 (right) [11, 12].

improvements and a 25% SAF share see emissions fall 40% by 2050. There would still remain 24 Mt CO_2 of aviation emissions, 25% of gross emissions, which would need to be offset to reach net zero. This pathway, and its embedded growth, has been criticised on the grounds that it privileges the aviation sector at the expense of everyone else [75].

The UK CCC finds that demand could be managed by "carbon pricing, a frequent flyer levy, fuel duty, VAT or reforms to Air Passenger Duty, and/or restricting the availability of flights through management of airport capacity" and are confident, based on discussions at the Climate Assembly, that this would be acceptable to the public.

A 'tailwinds' scenario sees demand falling 15% by 2050 and 95% SAF share, leading to nearly zero aviation emissions.

The International Energy Agency released an influential net zero study in 2021 [45]. For aviation, their scenario involves business travel and flights longer than 6 hours held at 2019 levels; regional flights shifted to high-speed rail where feasible; total travel to increase 70% between 2019 and 2050; advanced biofuel and e-fuel use to reach 50% by 2040 and 78% by 2050; governments to define their SAF strategies by 2025 at the latest; and carbon prices across all advanced economies rise to US$130 by 2030 and US$250 by 2050. Despite being enthusiastic about the practicalities of SAF—the IEA estimates that it will only add $10 to the price of a 1200 km flight in 2050—they are cautious on zero-emission aircraft, assigning them 2% of air travel in 2050.

The oil industry has a stake in increasing oil use in three key sectors, plastics, aviation, and shipping, as it is clear now that oil use in land transport will decrease even at present levels of climate action. The *BP Energy Outlook* for 2019 [11] saw total oil demand continuing to increase past 2040, with 64% of the increase coming from aviation (Fig. 2). In 2020 the *Outlook* introduced two new scenarios [12], "Rapid" and "Net Zero", along with BAU. They involve aviation nearly doubling by 2050, accompanied by 35% efficiency improvements and either 30% or 60% share of biofuels, along with a carbon price of NZ$250 by 2035 and NZ$380 by 2050 in developed countries. The prospects of such a carbon price applying to all international aviation in the developed world by 2035 are not addressed.

9 Airports

Aviation growth and airport expansion go hand-in-hand. Just as many airlines are state-owned (Wikipedia lists 119 of them, including Air New Zealand), so are many airports. In Europe, 59% of airports are wholly public-owned, 16% are private, and 25% are mixed. A 2018 report lists US$737 billion of airport construction projects in progress worldwide, of which just 7% were privately funded. Climate concerns have been raised against this tsunami of development. In the UK, where Heathrow's third runway has been controversial for decades, five environmental groups filed for a judicial review in 2018. All claims were dismissed. In February 2020, the Court of Appeal overturned this decision, finding that the Government's failure to take the Paris Agreement into account was unlawful; this decision was itself overturned in December 2020 by the Supreme Court. However, any application for the development will need to take into account the Government's aviation emissions strategy, which is still in preparation [30].

In New Zealand, Auckland Airport's long-held plans for a second runway have been put on hold by Covid, but a $1 billion airport redevelopment will go ahead. Wellington Airport is in the process of expanding; the first stage has been approved and is now under a court challenge. Christchurch Airport is proposing to build an entirely new international airport in Tarras, Otago, to serve the Queenstown–Wanaka region, again prompting environmental concerns. All three airports are partly publicly owned.

The paucity of government regulation or planning for aviation growth, particularly international aviation, or any guidance for the responsibilities of airports, is likely to become the subject of attention in these and in future development plans and in any possible court actions. Citizens and environmental groups can become directly involved in decision making related to airport construction.

In the UK, the Balanced Net Zero pathway of the UK CCC requires no net airport expansion in the UK; but eight airports are currently planning expansions.

New Zealand's current aviation emissions plan, prepared in 2016 as an ICAO requirement [57], takes a 'predict and provide' approach to growth and does not link airport capacity to emissions growth. It is woefully out of date, predicting international emissions in 2019 of 2.3–2.7 $MtCO_2$, depending on the rate of efficiency improvements, one-third less than the actual emissions of 3.9 $MtCO_2$. In 2021 NZ Airports supported this plan in their submission to the Climate Change Commission, and wrote that New Zealand airports have almost no contribution to aviation greenhouse gas emissions; growth and the level of flying were not mentioned as a factor in emissions [64].

10 Tourism

The growth of aviation has been tightly linked to the growth of tourism, both in New Zealand and worldwide. If aviation continues to grow, tourism will likely either continue in this role or become even more dominant. Through the 2010s the marketing of tourism continued to evolve, with talk of adventure and bucket lists for the upper middle classes in developed countries, and privilege and luxury for those on the highest incomes.

In January 2022, James Higham of the University of Otago co-edited a special issue of the Journal of Sustainable Tourism, writing in the introduction ("Code red for sustainable tourism") [38]

> Governments need to take a leading responsibility, but we cannot currently expect this to come from national tourism administrations. [...] Tourism administrations are guided by two key performance indicators: volume of (international) tourists, and volume of expenditure. Until their mandate changes, and they are required to develop metrics of success aligned with the Sustainable Development Goals and the Paris Agreement, any change will only happen as a result of other government departments that have a sustainability remit, particularly from those in charge of transport, energy and climate.

Indeed, New Zealand's own state tourism body has been slow to address emissions. The 2019 Government Tourism Strategy was focussed on 'sustainable tourism growth', but did not mention aviation emissions at all. A 2019 industry strategy ('now with sustainability firmly at its heart') briefly mentioned aviation emissions in the context of the threat that tourists might become environmentally responsible and not want to fly as far as New Zealand [80]. The Tourism Futures Taskforce, formed in response to Covid, announced that their final report would make recommendations on decarbonisation, but the group was disbanded [63].

Initiative therefore fell to the independent Parliamentary Commissioner for the Environment, Simon Upton, who in 2021 made tourism aviation emissions one of four key foci. In view of the particular political and practical challenges of the sector, he made two modest recommendations: one, to incorporate an emissions price into the cost of air travel from New Zealand, along the lines of the UK's departure levy, with revenues directed to decarbonisation R&D and Pacific climate finance; and two, to seek a plurilateral agreement, such as a climate club.

There has been no specific government response to these proposals. However, in May 2021 the Government agreed to re-set and rebuild tourism on a sustainable model and that the costs and negative impacts associated with tourism must be mitigated or priced into the visitor experience, and not funded by New Zealand rate and tax payers [63].

Gössling and Higham [32] have proposed three areas of action for national and regional tourism bodies. First, to lower emissions by focussing on closer markets, longer stays, and lobbying for regulation of aviation emissions. Second, to add value by promoting local and year-round activities. Third, to reduce financial leakage due to franchises, foreign ownership, travel booking sites, credit cards, and frequent flyer programs.

Internationally, the response has been no better. The WTTC, the peak global body for the travel and tourism industry, does have a net zero roadmap [84]: it assumes 83% growth from 2019 to 2050, and views the levers for aviation to be new technology, operational efficiency, and SAF—that is, not pricing or demand reduction. They remark that "especially in aviation, government support is key to realising the potential of the key levers."

At COP26 the "Glasgow Declaration on Climate Action in Tourism" was launched; signatories (travel and tourism companies) committed to preparing a plan within 12 months to halve emissions in 10 years and reach net zero by 2050. Scott and Gössling write [74]:

> The lack of specific actions in the Glasgow Declaration, and only unspecific commitments to measure sector emissions, reduce emissions, finance decarbonization and adaptation, and to collaborate on the net zero journey reinforce this

> concern [a worryingly unfamiliarity of the strategies by which Paris Agreement compatible energy-emission futures could be achieved and the potential implications for the tourism sector]. Many of these actions have been recommended over a decade ago, while recent studies demonstrate the persistent disconnect between tourism and climate policy at national scales. . . The incoherence of tourism and climate policy at national and international scales is an increasing vulnerability for tourism development.

They conclude that growth projections from the tourism sector are not compatible with net zero scenarios.

11 Substitutes

The natural experiment of Covid has revealed the startling availability of substitutes for flying, including flying less (see Section 14), videoconferencing (which, although not an exact substitute, has perhaps connected more people than flying ever did), substituting domestic for international tourism, and substituting local tourism for distant domestic tourism. All would repay further study. (An Aucklander with a second home in the ski resort of Queenstown could have higher emissions than the Londoner with a ski chalet in Switzerland interviewed by Cass *et al.* [20].)

Here we look at land transport as a substitute for domestic air travel.

The land transport options are private vehicles or public transport, bus and train. New Zealand's response is hampered by its extreme reliance on private cars—having heavily invested in infrastructure, with large schedule future investments and one of the highest car ownership rates in the world—and relative underinvestment in regional public transport.

Low-occupancy private cars are at present even higher-emission than flying and, despite some regulatory progress, likely to improve only slowly on a fleet-wide basis. This option is high-emission for the vast majority of car owners, and not available at all for people who do not own or car or drive, including many children, elderly, and some people with disabilities.

Regional public transport is limited to buses and trains. The passenger rail network, which had eight lines totalling 2700 km in 2001 and shrank to four lines and 1340 km by 2020, now just has three short routes left, Wellington–Palmerston North, Wellington–Masterton, and Hamilton–Auckland, totalling 348 km. For tourists, there is still the train from Christchurch to Greymouth. A private coach network still exists, but suffers from infrequent service, poor quality, substandard terminals, lack of connectivity, and lack of integrated ticketing.

If, in the UK, the rich take trains and the poor take buses [6], we suspect that in New Zealand the rich fly or drive and the poor take the bus or do not travel at all. Callister *et al.* [13, 15] make the case for the positive impact that a high-quality regional bus network would have on social and health inequalities, as well as on greenhouse gas emissions. Unfortunately, there is essentially no ongoing academic research, institutional monitoring, or coordinated planning of regional public transport in New Zealand.

Until the entire inter-regional transport system is considered as a whole, it will not be possible to assess the case for specific interventions such as rail electrification, resurrection of regional passenger rail, or an upgrade to higher-speed trains.

12 Emissions pricing

In New Zealand, domestic aviation is included in the Emissions Trading Scheme and in the carbon budgets set under the Climate Change Response (Zero Carbon) Amendment Act 2019. The first budget period covers 2022–2025. Prices rose from \$39/tCO_2 to \$85/tCOO in the year to 18 February 2022. Reserve units can be released (to be repaid later) if the price reaches \$70 in 2022, rising to \$110 in 2026. Carbon pricing, and the cap on emissions now in operation, can be expected to have an impact on domestic aviation.

Therefore, one view is that no further action is needed on domestic aviation.

However, a recent review of the literature on emissions pricing by one of the present authors [37] comes to an opposite conclusion, namely that emissions pricing can't do it alone. The behaviour change and technological transitions are too demanding in the required time frame, and prices are unlikely to be allowed to rise high enough. Complementary policies can deliver emissions reductions in a fairer and more orderly way, even under a cap on emissions.

Emerging plans for aviation adopt this view. For example, the EU is proposing to use both an SAF mandate and a fuel tax, in addition to a strengthened ETS and a cap on (EU) emissions. European support for rail is also linked to reducing intra-EU aviation. The IEA's net zero pathway also involves significant carbon pricing along with SAF and traffic regulation.

The elastic demand for aviation (see next section) indicates that aviation may be more responsive to pricing measures than areas with less elastic demand.

In this context the preferential tax situation that international aviation enjoys at present is an extremely significant obstacle to emissions reduction. The legal and jurisdictional obstacles to revising it are well known and were canvassed by, e.g., the Parliamentary Commissioner for the Environment [68]. They were a primary reason for his recommendation of a distance-based air passenger duty, as a pricing option that is legally available immediately. It could form the first step in a more comprehensive pricing regime.

Now that the EU is proposing to impose an excise tax on jet fuel the options politically open to other countries may increase.

13 The distribution of air travel

Climate solutions are often judged not just by whether they work—that is, by whether they reduce emissions—but also by whether they support a "just transition". As Sam Huggard of the New Zealand Council of Trade Unions writes [41], "the costs of the necessary changes that deliver all of us a more stable climate must be spread evenly and not fall heavily and disproportionately on workers, particularly those in carbon-exposed industries." New Zealand has joined international declarations to that effect, and set up a "Just Transitions" unit in the civil service, to ensure that the process is "fair, equitable and inclusive [and] that the Government works in partnership with iwi, communities, regions and sectors to manage the impacts and maximise the opportunities of the changes brought about by the transition to a low emissions economy."

All well and good. But what is "fair"? It is easier to detect things that are unfair. For example, a large and sudden petrol tax might be widely seen as unfair, as it would penalise people whose only available choice is to commute long distances in cheap gas guzzlers, while wealthy inner-city dwellers could continue to clog up the roads in electric cars.

We argue here that a just transition requires examining not just the impacts on workers in fossil fuel industries, and not just the impacts on poor people, who generally have low personal emissions and less ability to change them, but also at the rich high-emitters.

The Paris Agreement is founded on the principles of equity and the "common but differentiated responsibilities and respective capabilities" of the nations. Just what those are is open to debate, but this clause is generally held to mean that countries with high historical emissions—the ones that caused this problem—and rich countries, that have more scope and power to reduce emissions, should move faster than others.

How about within countries? Should rich people, and/or high-emitting people, pay proportionately more towards a country's transition, and reduce emissions more than others?

13.1 How are carbon emissions distributed?

To approach this question we first need to know the distribution of emissions within individual countries. A 2020 paper by Diana Ivanova and Richard Wood [47] looks at this for 26 EU countries. (The data comes from a survey of the expenditure of 275,000 households carried out in 2010, mapped into greenhouse gas emissions for each type of spending.)

Household emissions measure the emissions related to final consumption, wherever the actual greenhouse gases were emitted. The EU as a whole produces greenhouse gas emissions of 8 tCO_2e per person (cf. New Zealand 16.5 tCO_2e). But many EU countries effectively import emissions by buying things from other countries, such as China. Imports take the UK's 6.8 tCO_2e per person up to 9.6 tonnes, and Germany's 9.6 tonnes up to 11. New Zealand, a net exporter of greenhouse gases, consumes 12.5 tonnes per person. Of these 12.5 tonnes, 8.9 tonnes are assigned to households.

Ivanova and Wood found (see Fig. 3) that the lowest-emitting half of EU households emit an average of 5 tonnes per person; the middle 40%, 10 tonnes; the top 10%, 23 tonnes; and the top 1%, 55 tonnes CO_2e per person.

Air travel is strikingly unevenly distributed. 90% of EU households have air travel emissions averaging 0.1 tonnes per person; 9% average 0.8 tonnes; and the last 1% average 22.6 tonnes. Emissions from essential items (food and housing) increase more slowly that total spending: there's a limit to how much food a household needs. Emissions from goods, services, and land transport increase in tandem with total spending, while emissions from air travel increases very little in the lower quintiles but very rapidly in the top two. The authors write that this "confirms air travel as a highly carbon-intensive luxury" and describe transport as "one of the most unequally distributed and the strongest drivers of the carbon footprints of the rich".

They also report the distribution of household emissions across countries. For most countries (Fig. 3) these track very closely to the distribution of income.

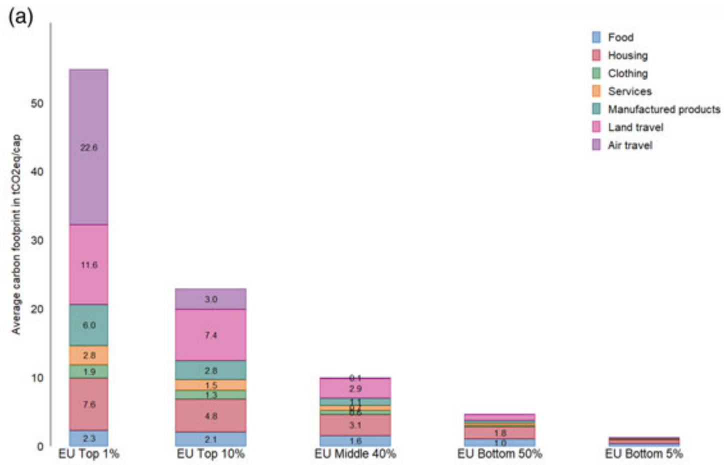

Figure 3: The 10th (pink oval), 25th (left box), 50th, average (orange oval), 75th (right box), and 90th (grey oval) percentiles of per capita household emissions for 26 European countries [47].

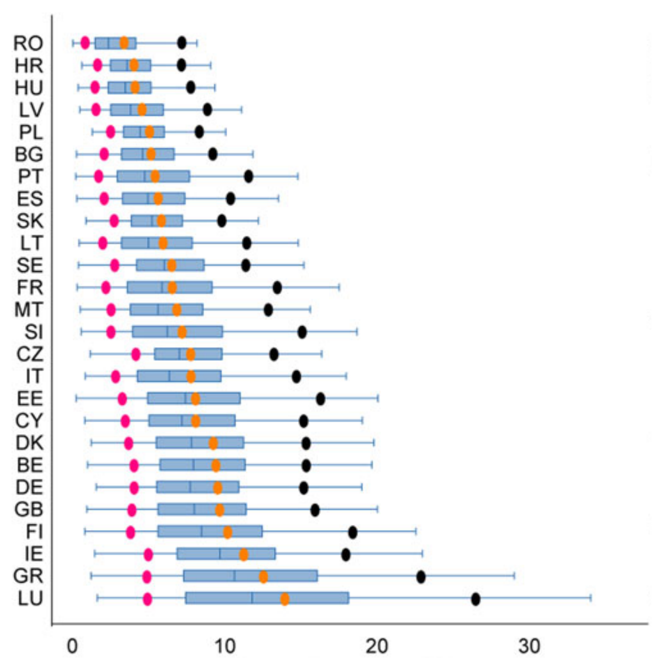

Figure 4: The 2010 consumption-based carbon footprint of EU household in 5 different quantiles and 7 different areas of consumption [47].

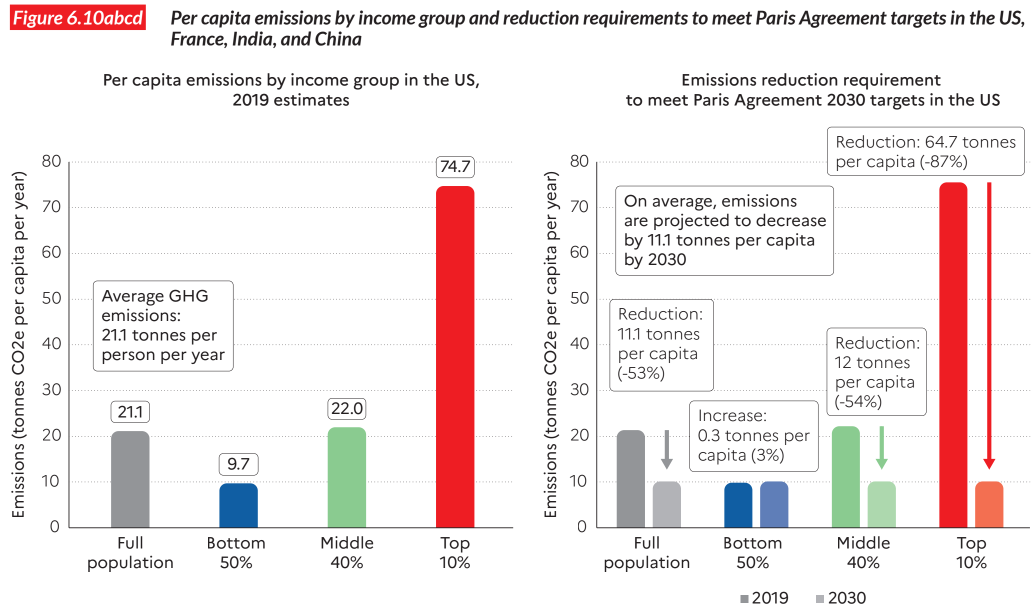

Figure 5: The emissions reductions for different income groups to meet Paris Agreement targets [16]. It is remarked in [16] that Canada, Australia, and New Zealand have similar carbon inequality levels to the US. [16]

The household emissions of the top 1% of EU households, 55 tonnes per person, may seem like a lot, but it is confirmed by other studies. Chancel and Piketty [70] found that the top 1% of Americans emit 318 tonnes CO_2e each per year. They put the emissions of the top 1% globally at 56 tonnes a year. (These figures are higher than those of than Ivanova and Wood, because they include all emissions and all income, not just those tagged to household consumption.)

The extremely skewed distribution of air travel is also reported by Gössling and Humpe [33]. They find that in any given year 1% of the world's population are extremely frequent flyers, emitting 10 tonnes CO_2 each on average and causing half of all aviation emissions; another 10% fly less and emit 1 tonne CO_2; and the remaining 89% do not fly at all. People with access to one of the world's 22,000 private jets could be associated with emissions of 7500 tonnes each. Even in rich countries like the US and Germany, and rich islands like Taiwan, less than half the population flies in any particular year.

A 2020 Oxfam report reaches a similar conclusion [31]. Oxfam find that the richest 1% globally have emissions of 74 tonnes of CO_2 per person on average, adding up to 15% of all emissions.

Although we may think of this as a rich country–poor country issue, a study by the World Inequality Lab, a global network of 100 researchers, found that inequalities within countries now represent the bulk of global emissions inequality [16]. The emissions reductions for different income groups to meet Paris Agreement targets are shown in Figure 5.

David Banister's *Inequality in Transport* [6] explores inequality in all forms of transport in the UK. He writes,

Table 3: Average household greenhouse gas emissions, in tonnes CO_2e per person for New Zealand [77] the EU [47].

	NZ 2017	EU 2010
Food	2.5	1.3
Housing	1.4	2.6
Clothing	0.24	0.6
Services	0.5	0.5
Manufactured products	0.95	1.0
Land travel	2.3	2.4
Air travel	1.0	0.5
Total	8.9	8.9

This figure of about a half of the adult population flying in any one year does not seem to have changed over the 10 year period (2002–2012). The growth in air travel appears to be coming from those who are already travelling and from this it can be inferred that passenger growth in recent years is coming at least as much from an increased flying frequency by those that do fly, as from a diminishing pool of non-fliers.

13.2 Application to New Zealand

Statistics New Zealand have calculated consumption emissions by household for 2017 [77]. They only report the average, not the distribution, which should be kept in mind when comparing their figures to the EU study until distributional data for New Zealand is available. Summary data is shown in Table 3.

The median take-home income in New Zealand is $41,500 per person, or adjusted for purchasing power, €19,300, above the UK and above the EU median of €17,300, and similar to Ireland and Finland.

One way to measure income distribution is by the ratio of the total income of the richest 20% to the total income of the poorest 20%. For New Zealand, this ratio is 5.6. For the UK is is 6.1, for Germany 4.4, and for the EU as a whole it is 5.0.

Therefore, a preliminary estimate is that the emissions of New Zealand households are distributed very unequally. Given our high air travel emissions, and the high elasticity of air travel amongst rich people, it is likely that New Zealand's top 1% and top 10% of households have very high emissions.

A second viewpoint considers New Zealand in light of global income distribution [70, 16]. A take-home income of $75,000 per person falls into the top 1% globally, which, as we have seen, have emissions of 56 tonnes per person. In New Zealand, 12.3% of households reach that income level. New Zealand's top 5% (take-home income of $100K per person) have similar purchasing power to the top 5% in the richer European countries (€50K). This also points to distributions similar to those found in the EU.

The implication is that other things being equal, an increase in inequality will be associated with an increase in flying, and in increase in GDP will be associated with a disproportionate increase in flying.

The discussion so far centres on inequality with respect to income or expenditure. As pointed out by Gebresselassie [28], many other factors are relevant: race and ethnicity, bodily ability, civic status, and age. For New Zealand we could add our location, our internal geography, our overall approach to transport planning and provision, our very high rates of immigration and emigration leading to globally-dispersed families, the Treaty of Waitangi, and our relationship with the Pacific. The *relative* inequality of aviation compared to other forms of transport and to other sources of greenhouse gas emissions is also relevant: an industry that more heavily serves the rich is less defendable that one that serves people more equally.

Nielsen *et al.* [65] study the role of high socio-economic status (SES) people in the climate crisis, writing

> High-SES status people often lead hypermobile lives, travelling by air for private and work-related purposes induced by income, business travel paid for by employers and expectations associated with status, work and ownership of multiple homes. Although the behavioural plasticity of air travel is under-researched, it may be substantial for high-SES people given the likelihood that the marginal benefits of each flight are lower for them than for lower-SES people who may fly only rarely to visit family. Changing social norms around hypermobility therefore appear to be an important potential lever to decrease GHG emissions from air travel.

They also consider that high-SES people affect the climate crisis and society's response to it more ways than just through their consumption, as in the example of air travel: as investors ("Efforts to support climate-compatible investing need to more narrowly target the highest-income investors, who control a large portion of the market and to date have been slow to change"), role models (e.g. through media exposure and the glamorisation of high-SES people), as owners and managers of organisations, and through lobbying.

Similarly, Cohen *et al.* [22] have described how travel is "glamorised by a range of social mechanisms, such as visualisations on social media that encourage mobility competition, frequent flyer programme status levels and the mass media and travel industry who depict tourism and business travel as desirable."

Our conclusion from this short survey is that inequality and fairness are one of the central issues in addressing aviation emissions.

13.3 Suggested responses

The authors of the studies cited have some suggestions.

Oxfam [31] call for

> special taxes or bans for high carbon luxury goods and services; wider carbon prices with pro-poor revenue recycling; broader income and wealth redistribution; or challenging stereotypes that promote growth and individual consumerism as normal, desirable, 'powerful' and 'masculine'... such measures may lead to a broader 'social tipping point' that makes reductions by other relatively high emitters more acceptable, challenges the political influence of high

> emitters, and sparks wider shifts in social, gendered and racial norms about endless consumption.

Gössling [33] writes:

> Emissions Trading Schemes are inappropriate for a sector in which the distribution of air transport demand and associated emissions is more highly skewed than in other areas of consumption. From a market-based viewpoint, a modest increase in the cost of air travel will not affect business travelers, who are causing disproportionally high emissions... [we] need to develop more complex transition policies for aviation.

Ivanova and Wood [47]:

> The contributions of land and air transport are disproportionally large among the top emitters. As land transport and, even more so, air transport are both highly carbon intensive and highly elastic, we would argue that significantly more needs to be done in these domains. Action here is likely to affect those with the highest footprints, incomes and expenditures most, but impacts on low-income groups are also key, as they have significant expenditure shares on land transport.
>
> Overconsumption and materialistic practices are not only damaging for the environment, but may also reduce psychological well-being. In order to reduce trade-offs between social and environmental goals, policies should target changes in higher-order need satisfiers, such as social structures and practices, and reimagine forms of need satisfaction within environmental constraints.

Chancel *et al.* [16] suggest a global progressive carbon tax for above-average emitters, to fund climate initiatives globally, or, failing that (for they acknowledge this is unlikely), progressive income taxes, or a global tax on air tickets of about €20 per 1000 km:

> Social movements in rich and emerging countries in 2018-2019 (including waves of protests against hikes in fuel and transport prices in Ecuador or Chile in 2019, and the Yellow Vest movements in Europe one year earlier) showed that policy reforms which do not properly factor in the degree of inequality in a country, and the winners and losers of these reforms, are unlikely to be publicly supported and are likely to fail... the scale of transformation required to cut greenhouse gas emissions drastically in rich countries cannot be attained if environmental and social inequalities are not integrated into the very design of environmental policies.
>
> One dimension which has been largely left aside by climate policies around the globe is addressing the large carbon footprints of the very wealthy. To accelerate carbon emissions reductions among the wealthiest, progressive carbon taxes can become a useful instrument. Progressive carbon taxation means that the rate of a carbon tax increases with the level of emissions or the level of wealth of individuals. Chancel and Piketty [70] made proposals along these lines, and also proposed specific taxes on luxury carbon-intensive consumption items. These can include business class tickets, yachts, etc.

Ralph Chapman, writing in a briefing paper for the OECD, writes [18]:

> Governments, both nationally and locally, seeking to constrain emissions of the population as a whole will in some form have to face the question of what they propose doing to regulate the very high emissions of the well-off, while at the same time ensuring that the transition process does not leave vulnerable groups worse off. One perspective on this is that dealing with the justice aspects of climate change is a pre-condition for proceeding in a responsible way with the climate transition. However, a rigid rhetorical position on this could stymie climate action. A perhaps more pragmatic position is that in any emergency, such as wartime, greater material sacrifices are expected of those with greater resources, and progressive taxation to finance mitigation investment is justified

The problem is not just that the high emitters have to pay more towards the transition, even more as a proportion of their income: that position is broadly accepted and is implemented in progressive income taxes. The harder problem is that they actually have to reduce their emissions. Ivanova and Wood [47] regard a target of 2.5 tonnes per person by 2030 as consistent with the Paris agreement. That means average emissions falling by 70%. But the bottom half of emitters can't reduce by very much at all, which means the top half have to do more. The situation is particularly extreme in aviation: only flyers can reduce their aviation emissions.

14 Flying less

> For surely there is no square mile of earth's inhabitable surface that is not beautiful in its own way, if we men will only abstain from wilfully destroying that beauty; and it is this reasonable share in the beauty of the earth that I claim as the right of every man who will earn it by due labour; a decent house with decent surroundings for every honest and industrious family; that is the claim which I make of you in the name of art. Is it such an exorbitant claim to make of civilization? of a civilization that is too apt to boast in after-dinner speeches; too apt to thrust her blessings on far-off peoples at the cannon's mouth before she has improved the quality of those blessings so far that they are worth having at any price, even the smallest.
>
> William Morris, 1881 [59]

> There is a good deal of a consensus as to what manner of things are wasteful. The brute fact that the word is current shows that. Without something of a consensus on that head, the word would not be intelligible; that is to say, we should have no such word.... It is because men's notions of the generically human, of what is the legitimate end of life, does not differ incalculably from man to man that men are able to live in communities and to hold common interests.
>
> Thorstein Veblen, 1934 [82]

Veblen (who coined the terms "conspicuous consumption" and "vested interests") had a long-running interest in waste and wasteful consumption. As remarked by Mitchell

[58] , Veblen's "treatment of a consumer-oriented society based on reckless waste by profit-hungry corporations underpins the root causes of environmental degradation and pollution, a premise even more applicable in today's global context of rapid environmental and socioeconomic change." However, most modern economists and policymakers do not engage in the question of what consumption is luxurious, wasteful, or unnecessary [79]. On the other hand, some go further and argue that overconsumption is built in to capitalism, and that therefore reducing emissions will require significant changes in work, production, consumption, advertising, and social norms [78].

The widespread realization of ecological overshoot and its catastrophic consequences, as well as humanity's acceleration of unsustainable resource use when confronted with the reality of climate change, has prompted a wide range of responses. (See, e.g., the recent presentation of Murphy *et al.* [62].) One framework is the "degrowth" movement, which calls for a decrease in global resource consumption until it reaches sustainable levels. (See Boston [10] for a comparison between green growth and degrowth.)

We focus here on an emerging body of work [36] that seeks to quantify the resource and energy use required for a commonly agreed decent standard of living. For example, Millward-Hopkins *et al.* [55] describe a lifestyle involving 5000–15000 km of annual travel per person, of which 1000 km is by air, and total energy consumption of just 15 GJ/person/year, one-twelfth of New Zealand's present primary supply of 180 GJ/person/year.

Akenji *et al.* [1] consider pathways that meet the required household emissions budgets under a 1.5 °C scenario. These see household emissions falling to 2.5 tCO_2/person by 2030 and to 0.7 tCO_2/person by 2050—a major challenge for New Zealand, currently on 8.9 tCO_2/person, as it is for other developed countries. It is argued that technological improvements in the emission-intensity of goods and services must be accompanied with major lifestyle changes towards reduced consumption. Reducing consumption has cobenefits, including regenerating biodiversity and safeguarding ecosystems. The extraction of materials, which rose from 27 billion tonnes a year globally in 1970 to 92 billion tonnes in 2017, and which continues to increase exponentially, must instead contract. The authors argue for a wellbeing economy that [1]

> fosters true quality of life factors such as a purposeful life, health care, healthy ecosystems and a stable climate, safe conditions in the workplace, education, and access to and participation in cultural activities and family life. The pandemic has shown us how important the above true quality of life factors are, no matter where we live. Countless research has shown that the priority given in contemporary society to growth at all cost, to profitability, and material consumption has not materialized in greater collective well-being or individual happiness for most.

The report adopts an "avoid, shift, improve" framework and studies policy options that could achieve them, including choice editing (removing the harmful consumption options), a social guarantee for fair consumption meeting human needs, sufficient levels for decent living, and carbon rationing. These are applied to food, housing, transport, goods, and services, with case studies of 10 countries.

In the UK, the "Jump" campaign `takethejump.org` asks people to sign up to six key lifestyle changes, one of which is to limit flights to one short-haul (< 1500 km) return flight every three years, or one long haul return flight every eight years, levels derived from a study of urban lifestyles compatible with 1.5 °C.

Applying the "avoid, shift, improve" framework to New Zealand aviation would likely reveal that the greatest opportunities lie in "avoid". "Shift" also has a role in domestic aviation, for example by improving land-based low-carbon public transport. In contrast, the aviation industry and current international policy development is almost entirely focussed on "improve". As we have learned from Covid, it is possible to avoid most international air travel with unexpected ease, whereas avoiding such a large proportion of emissions so quickly from food, housing, and goods and services without disastrous side-effects would be impossible.

Baledón *et al.* [7] and Higham *et al.* [39] examine aviation in light of the UN Sustainable Development Goals, noting that ICAO and the aviation industry claim that aviation contributes positively to almost all of the SDGs yet ignore the two most important factors, growth and emissions. Higham writes:

> . . . aviation is deeply embedded in not only the economic, but also the social, functions of global capitalism. Because air transport is so "tightly bound up with the reproduction and expansion of capitalist societies", there has been a reluctance to act on the environmental impacts of aviation. Rather than confront the problem of aviation emissions, the macro-level sociotechnical regime has been consciously developed to perpetuate growth in air travel. The aviation transport system serves as a public good that is simultaneously consumed by multiple actors (e.g., governments, corporations, exporters, and leisure travelers), both for productive (indirect) and final (direct) consumption.

It is difficult to define what flights, or what level of aviation, is considered 'essential'. The factor that air travel is a luxury good (i.e., its elasticity is greater than 1, averaging 1.5 in the EU [47] and 2–2.7 amongst upper income groups, but nearly zero amongst lower income groups) is one guide. Secondly, we consider the Ngā Tūtohu Aotearoa wellbeing indicators monitored by Statistics New Zealand, following international guidelines. While 81% of the population reported high overall life satisfaction in 2018, this rose to 84–86% in 2020–21, during a time when international travel was almost impossible (international passenger numbers fell 97.6% in the year to March 2021 compared to the previous year.) "High family wellbeing" rose from 83% in 2018 to 84–85% in 2020–21. A further measure, on 'leisure', is under development: it will measure people's amount of leisure time and their satisfaction with their amount of leisure time. It seems unlikely that international travel will impact on this score. Under the Material Wellbeing Index, ability to have a holiday away from home once a year scores one point (out of 35 points in total).

Cass *et al.* [20], in a study for Oxford University's Centre for Research into Energy Demand Solutions, consider the role of curbing excess energy consumption in a fair transition. After comparing ten possible definitions of 'excess', they conclude that

> excess is whatever people can agree it is, based on ideas of 'fairness' and 'just' levels of consumption that can be rationalised, defended, and justified to others. . . any policies that are used to target excess consumption and excessive

> consumers must be similarly reasonable and justifiable, based on the principles of deliberative democracy and exploring options, impacts, and fairness with members of the public.

For aviation, they write that

> it would be both more effective and equitable to curb high-end consumption and consumption of luxury items such as flights than to target necessities across the whole income spectrum.... Since air travel is so unequally distributed in society, any increase in aviation costs would be progressive in the sense of impacting those with more wealth. From that perspective, it seems socially unjust that aviation fuel remains untaxed, compared to domestic or motor fuels. However, higher aviation costs would still have an impact on the infrequent flights of the less wealthy. A frequent flyer tax would have more progressive and fairer distributional impacts.

They explore these ideas through interviews with people living in high-consumption households.

Other research from the Centre emphasizes the importance of demand reduction in meeting net zero targets, concluding: [8]

> Meeting carbon budgets aligned with net-zero by 2050 without substantial reductions in energy demand is extremely difficult and undesirable... Reducing energy service demand is particularly useful in "hard to mitigate" sectors such as steel production, aviation and agriculture.

Chapman *et al.* [17] report on a UK survey that found that a frequent flyer levy was preferred over all other suggested options (a tax on jet fuel, a limit to total flying, VAT on tickets, and doing nothing); they analyse the impact of a pricing scheme which combines an ETS charge with a frequent flyer levy.

A large survey of public support for aviation policy measures in Sweden [49] found that perceptions of whether a policy is fair and effective were by far the most important variables.

The UK Citizen's Climate Assembly considered aviation in detail. From fourteen possible policy options, the four that had more than 40% support from the assembly were to speed up technological solutions (53%), influence the rest of the world (50%), improve non-flying alternatives (50%), and that frequent flyers and those who fly further should pay more (44%). A modest growth, high-tech aviation future was the first choice of 39%; low- or degrowth futures (–17% to 25% growth by 2050) were the first choice of 58%. A future with 63% aviation growth by 2050 was the first choice of 3% of the participants. (Recall that the IATA forecasts traffic growth of 120% worldwide).

The French Citizen's Assembly for Climate recommended by an 88% majority to increase carbon charges on air travel, to prohibit airport expansion, to ban domestic flights where a train alternative of less than four hours is available, to offset all remaining emissions, and to support R&D into biofuels.

This suggests that when presented with detailed information about the impact of flying and possible ways to address it, and having considered these in detail, the public include pricing measures and demand restraint in their preferred solutions. This was a factor in the view of the UK CCC that restraining demand growth would not be difficult.

15 What is a fair share for aviation emissions?

There is no universally agreed approach to this question.

One possible avenue follows the carbon budgets of the IPCC [42]. Taking the remaining global carbon budgets for 1.5 °C (resp. 1.7 °C, 2 °C), and allocating aviation 2.4% of global CO_2, leaves a carbon budget of 9600 (resp. 16800, 27600) $MtCO_2$.

In 2019, New Zealand was responsible for 0.54% of global aviation emissions. (cf. 0.07% of global population and 0.10% of global CO_2). Retaining this share leaves a carbon budget of 52 (resp. 91, 149) $MtCO_2$ for New Zealand aviation. Assuming traffic recovers to 2019 levels by 2024 before reducing by 50% (resp. 100%, 150%) by 2050, would see the carbon budget for 1.5 °C exhausted by the early to mid 2030s in all three scenarios (see Fig. 6). However, reducing emissions by 150% would meet the 1.5 °C budget on average in the 2040s.

However, there is no clear justification for a 2019 baseline, which would act to grandfather in the very rapid increases of the late 2010s. The Paris Agreement acknowledges the principles of fairness, responsibility, and capability, and calls for the highest ambition. Adopting a 1990 baseline, when New Zealand was responsible for 0.41% of global aviation emissions, would reduce its aviation carbon budget by a quarter, leaving just 39 $MtCO_2$ for 1.5 °C.

Under the carbon budget approach, very sharp reductions in emissions are needed. However, earlier action—especially in the 2020s—makes meeting the budgets easier. Ensuring that 2019 levels are never regained would make meeting carbon budgets significantly easier.

Fairness towards future generations points towards relying as little as possible on carbon sequestration (whether by forestry or CCS) and focussing on absolute emissions reductions.

Fairness to all New Zealanders requires taking the (at present) highly unequal distribution of air travel, and the luxury and inessential nature of some air travel, into account, implying that aviation emissions should reduce more rapidly than other, more equal and more essential sectors.

In place of these considerations, the dominant narrative thus far has been that, first, aviation is "hard to abate"; second, that it should be allowed to grow and to consume an ever larger share of gross emissions; and third, that it should not be subject to the "polluter pays" principle. However, it is difficult to find detailed arguments for the connections between these three things, involving, for example, comparisons with other "hard to abate" sectors like metals, cement, and car dependency, their role in sustainability and wellbeing, and the availability of substitutes. Instead the aviation industry provides assertions ("The necessity and value of aviation to New Zealand's economy and to New Zealanders cannot be over-stated" [64]) and slogans ("aviation is the business of freedom" (IATA)).

The experience of Covid indicates that even an almost complete stop to international aviation had surprisingly little effect on the economy (GDP grew 3.4% from 2019 to 2021) or, as we have seen, effects on wellbeing. However, there are confounding effects for both of these, namely government economic stimulus, social solidarity, and knowledge of the

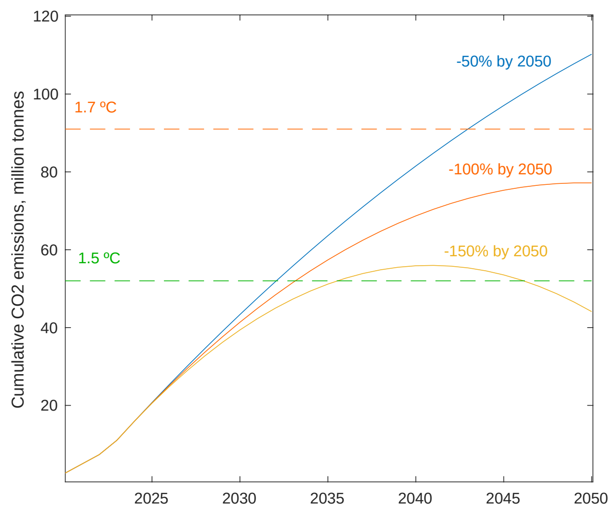

Figure 6: Idealized pathways for future cumulative CO_2 emissions from New Zealand aviation, 2020–2050. The model assumes that emissions are 50% below 2019 levels in 2020–2022, 25% below in 2023, and return to 2019 levels in 2024 before they start reducing linearly. The dashed lines show the carbon budgets under two global temperature targets and constant shares of aviation emissions globally and nationally.

health risks of travel. Substitutes including telecommunications, domestic tourism, and local tourism were adopted. The natural experiment of Covid restrictions could repay a more detail study.

Taken together, these considerations imply that a naive “net zero by 2050” pathway, heavily reliant on offsetting and nonexistent technology, would not sufficiently fair or ambitious for New Zealand.

16 Conclusions

The three main factors that will affect aviation emissions over the next 30 years are efficiency, alternative fuels, and total travel. There is reasonable agreement that zero-emission aircraft will play a limited role in this time span.

Efficiency gains are to be encouraged, and there is reasonable agreement that some gains can be expected. They could be encouraged by carbon pricing, by an SAF mandate, or by banning the operation of high-emission aircraft models.

There is wide disagreement over the potential for alternative fuels and for the speed with which they can be supplied. Proposals for SAF vary widely (see Table 4). Many rely on technology which is not yet in commercial use, which makes estimating costs and risks difficult. The lifecycle emissions and renewable energy inputs to produce the fuels are also uncertain. And of course, the amount of SAF required depends on the amount of fuel required, i.e., on aircraft efficiency and total distance travelled. The total resources required for high growth, high SAF scenarios are very significant.

Table 4: The eleven proposals or estimates discussed in the text. The UK CCC data is their 'Balanced Net Zero' pathway; IEA and BP data are their net zero models. The ICCT estimate is based on the potential maximum technology and feedstock supply. The SAF proportions do not take into account the lifecycle emissions of the fuels (e.g. land use, processing, infrastructure, renewable energy).

Scope	Study	Proposed SAF proportion	Traffic growth by 2050
EU	Fit for 55	20% by 2035, 63% by 2050	
EU	ICCT	20% by 2035	
UK	Jet Zero	14% by 2050	54%
UK	CCC	25% by 2050	25%
UK	Absolute Zero		−100%
world	IEA	50% by 2040, 78% by 2050	70%
world	BP	60% by 2050	80%
world	IATA	65% by 2050	120%
world	Klöwer	95% by 2050	110%
world	Klöwer	0	−50%
New Zealand	Air NZ	86% by 2050	75%

Total travel also varies widely in the different pathways. The high growth scenarios are dubious for a number of reasons.

1. They rely on significant amounts of offsetting (which is not sustainable in the long term) or permanent carbon dioxide sequestration (which is unproved at commercial scale)

2. They rely to some degree on technological solutions, which may not be available quickly enough.

3. They have not been found to be consistent with the Paris Agreement, nor to demonstrate its principles, including fairness, responsibility, capability, and highest ambition.

4. They do not take into account the need to reduce fossil fuel burning drastically in the coming decade.

5. They rely on a naive interpretation of the claim that aviation is "hard to abate" which has not been sufficiently justified or interrogated—for example, by comparing to other sectors which are also challenging technologically. As things stand, climate safety points towards phasing out "hard to abate" sectors where possible.

6. Other things being equal, a net zero pathway with high growth will result in greater total emissions than a net zero pathway with low or negative growth. Under a finite carbon budget, it is the total emissions that are relevant, not the endpoint.

7. A net zero pathway with high growth involves devoting greater total resources (of renewable energy, land, and construction of SAF facilities) than a pathway with low or negative growth. In a transition in which all of these resources are constrained, there is a need to prioritise resources.

8. The high-growth scenarios, which generally show a continued acceleration of growth continuing past 2050, do not address fundamental questions of sustainability, even if net zero were to be reached.
9. They do not take into account the distribution of aviation and its resulting implications for climate justice.

We have surveyed a range of factors which should be considered as New Zealand prepares an "ambitious and concrete national action plan to reduce aviation emissions" this year.

The past two years have seen a virtual revolution in the international context as numerous international bodies have aligned behind a vision of net zero aviation by 2050.

The main areas of difference between industry- and non-industry-led scenarios is that the former involve more growth—indeed, they often consider growth rates as given and not as a key variable—and reject emissions pricing. Some industry proposals seek government funding and subsidies. Some also reject regulation and rely on voluntary action and aspirational goals.

While pricing international aviation is difficult, which would by itself tend to point more towards regulation of emissions, some jurisdictions are now starting to consider it. We anticipate that, as in many other sectors, a combination of pricing and complementary policies will be needed [37].

We conclude that a national action plan should include consideration of the following factors.

1. Adoption of the "avoid, shift, improve" framework;
2. emissions pricing and the "polluter pays" principle;
3. where pricing is not achievable, regulation of emissions and emissions intensity;
4. the non-CO_2 effects of aviation;
5. the distribution of flying in a climate justice perspective;
6. the availability of substitutes, and the national strategies for those substitutes (e.g., regional public transport);
7. coordination with the tourist industry;
8. the rate of growth or degrowth;
9. the role of airports;
10. timely implementation;
11. emphasis on proven technologies, such as using the most efficient existing aircraft filled as much as possible;
12. the lifecycle emissions and resource requirements of SAF, including land use, renewable energy, and facility construction;

13. a fair share for aviation emissions with reference to the whole population and economy, not just to frequent flyers and the aviation industry; and
14. the transition to true sustainability respecting the rights of future generations.

Two key events of the past half decade reinforce the urgency of the task. The first is the proven ability of the New Zealand aviation industry to increase emissions at a staggering rate when unregulated, as observed from 2015 to 2019; the second is Covid. Ensuring that aviation emissions remain permanently well below 2019 levels requires urgent action, but would make the longer-term task significantly easier.

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