Raising the public visibility of aviation emissions

A report by AEF for the Foundation for Integrated Transport
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Summary

Aircraft carbon emissions globally are predicted to double in the next few decades, while even in the relatively mature UK air travel market, the Government's aviation demand forecasts acknowledge that emissions will be higher in 2050 than they are today. Reducing aviation emissions will require a combination of cleaner fuels and technologies on an unprecedented scale, policy measures and economic instruments to manage demand, and cultural changes around flying habits.

Public concern about the environment is at an all-time high in the UK. But while most people are probably aware that aviation contributes to climate change, there is far less understanding about the scale of impact of an individual flight or how it compares with other activities. Identifying this opportunity to engage with the public on the climate change impact of aviation emissions, FIT commissioned AEF to prepare an initial report, with background information and references, to support an outreach project.

The aims of the project are as follows:

1) Improve understanding of, and publicise, the climate change impact of aviation emissions, including the additional climate change effects of water vapour, contrails and nitrogen oxides.
2) Tabulate readily available information on the climate change effects of flights of different lengths, so that people contemplating, say, a weekend in Prague, a holiday in south east Asia or a business trip would know the consequences.
3) Make clear comparisons with emissions from other activities (heating homes, eating meat, etc) and average total per capita emissions (UK, US, world and Africa).
4) Clarify the carbon emissions per passenger for take-off, cruising (per thousand kilometres) and descent respectively for different sizes and types of aeroplane.
5) Calculate the extra emissions from first class over other premium classes.

The climate change impact of aviation

Globally, aviation CO_2 emissions in 2018 were approximately 1Gt (a thousand million tonnes), two and half times more than the entire UK economy emitted last year. UK air travellers are set to have a growing impact on climate change. More international trips were made last year by passengers travelling on UK passports than by people of any other nationality, and UK passenger numbers are forecast to increase.

In addition to CO_2, aviation has impacts in the upper atmosphere that exacerbate global warming. While these non-CO_2 impacts all have different lifetimes in the atmosphere, and can interact to have both warming and cooling effects, the UK Government department for Business, Energy and Industrial Strategy (BEIS) recommends to businesses that when reporting the CO_2 emissions from flying, they should multiply total CO_2 emissions by 1.9, to reflect the best estimate from IPCC scientists about the total non-CO_2 impact of flying. AEF recommends adopting this figure when estimating the total climatic impact of a flight.

The climate change effects of selected flights of different lengths

AEF used CAA and UN data to estimate the climate impact of a range of flights based on popularity with UK passengers, while aiming to ensure some regional diversity. The calculations are based on a typical aircraft operating on a given route and apply a 1.9 multiplier to account for non-CO_2 impacts.

- For a domestic return economy flight between Aberdeen and Heathrow, the total emissions impact per passenger is estimated at 325kgCO_2 (0.3 tonnes).
- For a short haul return economy flight between Newcastle and Tenerife, the total emissions impact per passenger is estimated at 913kgCO_2 (0.9 tonnes).
- For a long haul return economy flight between Gatwick and Montego Bay in the Caribbean, the total emissions impact per passenger is estimated at 1964kgCO_2 (2 tonnes).

Seat class has a significant impact on emissions per passenger given the greater space occupied as a result of flying business or first class. We estimate that flying premium economy generates 1.5 times the emissions of flying economy, business class generates twice the emissions and first class four times the emissions.

Comparing the impact of flying with the emissions from other day to day activities, and with average per capita emissions from selected countries

The UK has one of the widest ranges of carbon footprints in the EU, so it is hard to settle on figures for average consumption. Nevertheless we have attempted to estimate the relative impact of flying compared with some day-to-day activities, particularly those that people generally understand to have high climate impacts.

- Taking a single long haul return flight from Birmingham to Delhi (emitting just over 1 tonne CO_2 adjusted for additional climate impacts) would wipe out all the savings made by switching from moderate meat consumption to being vegan for a year.
- Annual emissions per capita in the UK from driving are around 1tonne CO_2, equivalent to the emissions of a single long haul return flight.
- Flying economy from London to Paris generates 27 times the CO_2 emissions of making the same journey by Eurostar (53 kg compared with 2 kg for a one-way trip)
- One return flight between Manchester and Southampton generates more emissions than running a tumble drier for a year (0.18 tonnes).
- A return business class flight between the UK and Delhi generates more emissions (at just over 2 tonnes) than the annual average emissions per capita in India (1.8 tonnes).

Introduction and context

Aircraft carbon emissions globally are predicted to double in the next few decades, while even in the relatively mature UK air travel market, the Government's aviation demand forecasts acknowledge that emissions will be higher in 2050 than they are today. This 'direction of travel' is out of step with the action needed to meet the UK's existing target under the Climate Change Act and threatens our ability to achieve the new political commitment to net zero greenhouse gas emissions by 2050. Reducing aviation emissions will require a combination of cleaner fuels and technologies on an unprecedented scale, policy measures and economic instruments to manage demand, and cultural changes around flying habits. Growing public awareness of climate change generally, and of aviation's contribution to the problem, has already led to a small but growing culture of 'flying shame' and public pledges to fly less.

It is too early to predict whether this will result in long-term or mass behavioural change, but with public concern about the environment[1] at an all-time high in the UK, accurate information to support people in making personal choices about how they travel and how they can make lifestyle adjustments to lower their carbon footprint seems timely. While most people are probably aware that aviation contributes to climate change, there is far less understanding about the scale of impact of an individual flight or how it relates to other activities.

A poll in November 2018 by YouGov of 1,750 British adults for 10:10 Climate Action found a widespread lack of awareness about the level of damage air travel inflicts on the climate. When asked to select one or two actions from a list that would have the biggest impact on reducing an individual's carbon footprint, only 15% correctly identified taking one fewer transatlantic flights, whereas 37% correctly identified "going car free" as effective. The most frequent flyers ranked "upgrade to more efficient light bulbs" above "reducing air travel".

The poll found that support for policies to tackle the climate change impacts of air travel is much higher amongst people who are aware of the extreme damage to the environment caused by flights.

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[1] https://www.theguardian.com/environment/2019/jun/05/greta-thunberg-effect-public-concern-over-environment-reaches-record-high

Project aim #1: Improve understanding of, and publicise, the climate change impact of aviation emissions, including the additional climate change effects of water vapour, contrails and nitrogen oxides.

- Globally, aviation CO_2 emissions in 2018 were approximately 1Gt (a thousand million tonnes), two and half times more than the entire UK economy emitted last year.
- In the UK, aviation emissions (generated by all flights departing from UK airports) are approximately 37MtCO_2. This is more than double the 17Mt the sector emitted in 1990. Emissions peaked at around 38Mt in 2006, before falling to a recent low of below 34Mt in 2010. Since then emissions have been gradually increasing again.
- According to IATA (the global airline trade association), more international trips were made last year by passengers travelling on UK passports than by people of any other nationality.
- UK passenger numbers are expected to grow from 292.2 million passengers per annum (mppa) today, to 435mppa by 2050. Government forecasts assume that the corresponding CO_2 impact will be 37Mt without Heathrow expansion and 40Mt with it. This assumes some use of alternative fuels, a shift to larger planes, and a total 48% improvement in aircraft efficiency between 2016 and 2050.

Aviation has impacts on the climate in addition to those from its CO_2 emissions. As early as 1999, the Intergovernmental Panel on Climate Change identified that emissions of nitrogen oxides (NO_x), water vapour and particulates at altitude, and the formation of contrails, have a net warming impact on global temperatures.

The impact of NO_x emissions, released as part of the combustion process, depends on altitude and location. In the upper atmosphere, these NO_x emissions react to increase ozone concentrations, or, largely in the southern hemisphere, to decrease methane concentrations. As methane is a greenhouse gas, reducing concentrations has a global cooling effect. But with the majority of flights taking place in the northern hemisphere, this is more than offset by the growing contribution to ozone, and overall, NO_x has a net warming effect. Similarly, when flights transit cold, saturated air masses, particulate emissions from aircraft engines can lead to the formation of condensation trails (contrails). Persistent contrails have been linked to increased cirrus cloud formation.

The overall effect was, in 1999, estimated to be a net warming that, based on historical emissions was a factor of two to four times greater than that from aircraft CO_2 emissions alone. Since publication of this analysis, further research has focused on improving the understanding and certainty of specific impacts but the accepted scientific consensus is that non-CO_2 emissions are major contributors to aviation's total climate impact. IPCC's latest Assessment Reports estimate that, using the radiative forcing (RF) metric[2], the total climatic impact of aviation has, to date, been 1.9 times greater than the sector's CO_2 impact, excluding the potential impact of additional cirrus cloud formation.

The radiative forcing metric is based on historical emissions and is not regarded as suitable for forecasting future impacts as the relationship between non-CO_2 and CO_2 emissions may vary with time. This uncertainty, and the need for further research to find an appropriate metric for future emissions, has

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[2] Radiative forcing is a measure showing changes in the Earth's energy balance between incoming solar radiation and outgoing IR radiation. Greenhouse gases act as forcing agents that affect the global energy balance.

been cited as a reason for delaying the introduction of any policy measures to limit aviation's non-CO_2 impacts. The scientific community is currently working on alternative temperature-based metrics, including the Global Warming Potential ("GWP") measured over 20 and 100 years. Latest scientific estimates show the likely total GWP for all aviation emissions is in the range of 1.9-2 times that of CO_2 (a figure very close to the historic RFI).

Many carbon calculators apply a multiplier to take account of non-CO_2 impacts. In fact, the Government's GHG reporting guidelines, published by the Department for Business, Energy and Industrial Strategy (BEIS), recommend that companies calculate their emissions from air travel based on total emissions: "*Organisations should include the influence of radiative forcing RF in air travel emissions to capture the maximum climate impact of their travel habits. However, it should be noted that there is very significant scientific uncertainty around the magnitude of the additional environmental impacts of aviation."*

Recent scientific studies are constantly adding to our understanding of non-CO_2 impacts, and some studies estimate the impacts to be greater than previously thought. For these reasons, some calculators apply a precautionary principle and use a higher number. For example, Atmosfair uses a multiplier of 3. For the purposes of this analysis, AEF recommends using 1.9, reflecting the most recent BEIS recommendation to businesses and the latest published figure from IPCC.

Project aim #2: Tabulate readily available information on the climate change effects of flights of different lengths, so that people contemplating, say, a weekend in Prague, a holiday in south east Asia or a business trip would know the consequences.

Methodology

Using CAA airport data for UK scheduled and charter operations in 2018, we have selected illustrative domestic and international routes based on popularity with UK passengers, while aiming to ensure some regional diversity.

The CO_2 figures were obtained from the UN's International Civil Aviation Organisation's (ICAO's) Carbon Calculator[3] and multiplied by a factor of 1.9 to present the total climatic impact of the flight (see Project Aim #1 for the policy justification). ICAO's calculator takes a four-stage approach:

- 1. Estimation of the aircraft fuel burn from origin to destination airport
- 2. Calculation of the proportion of the total fuel burn associated with passengers, derived from Revenue Tonne Kilometre (RTK) data (fuel burn associated with belly freight on board is not considered)
- 3. Calculation of the seats occupied using load factor data
- 4. CO_2 emissions per passenger = (Passengers' fuel burn * 3.16[4]) / Seats occupied

The full methodology is published on ICAO 's website[5].

The results are presented for domestic routes in Figure 1, short-haul international in Figure 2 and long-haul international in Figure 3.

[3] https://www.icao.int/environmental-protection/CarbonOffset/Pages/default.aspx

[4] Fuel burn in kg is converted to CO_2 by multiplying by a factor of 3.16

[5] https://www.icao.int/environmental-protection/CarbonOffset/Documents/Methodology%20ICAO%20Carbon%20Calculator_v10-2017.pdf

Figure 1: Illustrative calculations of the total climate impact of a selection of domestic on a per passenger basis

Route by airport pair (total passengers travelling in both directions)		Passengers (in 2018)	Distance between airports - single journey (km)	Typical aircraft	CO_2 return per passenger (kg)	Total impact equivalent to CO2 in kg using 1.9 multiplier for non-CO_2
Aberdeen	London Heathrow	675,816	647	A320	171.8	326.42
Belfast International	Liverpool John Lennon	498,603	264	A319	102	193.8
Manchester	Southampton	220,742	274	Dash 4 (turboprop)	97	184.3

Figure 2: Illustrative calculations of the total climate impact of a selection of international short-haul routes on a per passenger basis

Route by airport pair (total passengers travelling in both directions)		Passengers (in 2018)	Distance between airports - single journey (km)	Typical aircraft	CO_2 return per passenger (kg)	Total impact equivalent to CO2 in kg using 1.9 multiplier for non-CO_2
Birmingham	Larnaca, Cyprus	130,075	3,396	B737-800	503	955.7
Bristol	Barcelona	201,233	1,178	Airbus A320	252.4	479.6
Edinburgh	Milan Malpensa	164,921	1,423	Airbus A319	294	558.6
Leeds-Bradford	Amsterdam	252,180	460	B737-800	164.8	313.1
London Gatwick	Marrakesh	355,350	2,264	A320	367.2	697.7
London Heathrow	Nice	553,540	1,040	A320	242.4	460.6
London Luton	Athens	99,859	2,440	A321	383.8	729.22
London Stansted	Dublin	898,295	470	B737-800	120	228
Newcastle	Tenerife	246,944	3,230	B737-800	480.4	912.76

Figure 3: Illustrative calculations of the total climate impact of a selection of long-haul routes on a per passenger basis

Route by airport pair (total passengers travelling in both directions)		Passengers (in 2018)	Distance between airports - single journey (km)	Typical aircraft	CO_2 return per passenger (kg)	Total impact equivalent to CO2 in kg using 1.9 multiplier for non-CO_2
Birmingham	Delhi	70,715	6,795	B787-800	547.4	1,040
Edinburgh	New York JFK	135,142	5,220	B757-200	605.6	1150.6
London Gatwick	Los Angeles	283,710	8,795	B787-900	773.4	1,469.5
London Gatwick	Montego Bay	213,295	7,564	B747-400	1,033.6	1,963.8
London Heathrow	Bangkok	828,432	9,571	B777	855.4	1,625.3
London Heathrow	Beijing	530,314	8,150	A330-300	649.4	1,233.9
London Heathrow	Buenos Aires	173,064	11,130	B777	1184.4	2,250.4
London Heathrow	Johannesburg	933,357	9,069	A380	1024.1	1,945.8
London Heathrow	Lagos	374,601	5,002	A330-300	719.7	1,367.43
London Heathrow	Sydney (via Singapore)	192,603	17,165	B777 / A380	1,748.4	3,322
Manchester	Dubai	1,000,214	5,560	A380	718.4	1,365

The information presented in these tables includes representative aircraft operating on these routes to help explain the results (see discussion below). In terms of presenting this information to the public, we recommend a simplified approach along the following lines:

> A return economy class flight from London's Heathrow Airport to Beijing emits 649kg of CO_2, or the equivalent of 1,234kg of CO_2 once aviation's additional impacts on climate change are taken into account.

Why don't the results in Figure 1 vary linearly with distance?

The routes were chosen to illustrate the general scale of CO_2 emissions associated with flying to a range of destinations. However, a comparison of routes over similar distances shows differing results for the associated carbon emissions. Why? The calculator uses up-to-date operational data covering many variables including:

- Aircraft type: older technology will not be as efficient per passenger/km as newer aircraft types; turbo-prop aircraft generally have greater efficiency than jets.
- Airport congestion: additional holding for an arrival slot can increase emissions flight time and distance flown, resulting in greater fuel burn.
- Load factors – in 2018, average occupancy was 81.9%, but load factors vary between routes and carriers.

A good example of how these variables can impact the results can be seen by looking at the London to New York route. Flying London Heathrow to New York JFK produces 671.3kg of CO_2 for a return economy flight, but flying from London Gatwick produces only 579.4kg. The difference can be attributed to the airline Norwegian operating low cost transatlantic operations from Gatwick which offer more seats per flight than on the Heathrow option, and using planes that are on average just 3.6 years old.

Does the choice of calculator matter?

Yes. In addition to the ICAO Calculator, the public can choose from a wide range of online calculators to estimate the emissions from their flight. Until recently, a lack of publicly available data on the fuel burn of different aircraft types made most calculators reliant on limited operational data that, in some cases, had been published over a decade ago. In contrast, the ICAO calculator was able to draw on information reported by states as well as route-specific data relating to load factors. The introduction of market-based measures for tackling aviation emissions has improved the situation with respect to available data. Greater airline disclosure of fuel burn and carbon emissions to meet reporting requirements under the EU Emissions Trading System, together with estimation tools to help small operators calculate the emissions on routes flown, have vastly improved the availability of data that calculators can use to improve their accuracy.

Two of the most commonly used calculators are Atmosfair and MyClimate. Both have different strengths. For example, My Climate includes a figure for carbon associated with the refining and transport of kerosene, as well as its combustion, automatically uses a multiplier of 2 to account for non-CO_2 impacts, and includes the estimate of the carbon associated with the manufacture of aircraft and the airport infrastructure. Atmosfair on the other hand applies a multiplier of 3 to all flights attaining an altitude of 9,000m or higher, to provide a conservative estimate of non-CO_2 effects, and tries to help consumers put the calculation in context by comparing it with, for example, the annual emissions of someone in India. Neither of these calculators are able to draw on the full range of data available to ICAO however.

The following table shows how the results compare on two selected return routes, London Heathrow to New York JFK and Manchester to Milan:

	Return Economy Journey		
Route:	ICAO tCO_2	MyClimate tCO_2e	Atmosfair tCO_2e
London Heathrow to New York JFK	0.671	1.8	2.863
Manchester to Milan	0.261	0.472	0.56
Adjusted for CO_2 emissions only:			
London Heathrow to New York JFK	0.671	0.9	0.954
Manchester to Milan	0.261	0.236	0.186

BEIS, meanwhile, produces annually updated "emission factors" to assist companies with GHG reporting. The 2019 methodology and reporting figures were published in June 2019[6]. This methodology uses UK CAA airline reporting data and emission factors calculated using the EUROCONTROL small emitter's tool, which provides fuel burn over average flights for different aircraft. This has been validated using actual fuel consumption data from airlines operating in Europe.

BEIS provides the following **emission factors for air travel:**

				With RF	Without RF
Activity	Haul	Class	Unit	CO_2 kg	CO_2 kg
Flights	Domestic	Average passenger	Pass-km	0.25355	0.13345
	Short-haul to/from UK	Average passenger	Pass-km	0.15753	0.08291
		Economy passenger	Pass-km	0.15495	0.08155
		Business passenger	Pass-km	0.23243	0.12233
	Long-haul to/from UK	Average passenger	Pass-km	0.19464	0.10244
		Economy passenger	Pass-km	0.14906	0.07845
		Premium economy passenger	Pass-km	0.2385	0.12553
		Business passenger	Pass-km	0.43229	0.22752
		First passenger	Pass-km	0.59626	0.31382

Applying the BEIS methodology 'without RF' to the London to New York example, a return economy flight, a distance of 5,567km each way, is estimated to produce 0.873 tCO_2.

[6] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2019

Comparisons with MyClimate, Atmosfair, and BEIS, suggest the ICAO Calculator uses the most conservative assumptions. On the other hand, the ICAO Carbon Calculator has access to up to date operational data, and is the official calculator for the United Nations Climate Neutral initiative (it is used by the UN family to calculate staff and meeting travel emissions). It is used in this report as a default, but all the estimates of emissions can be recalculated using any of these approaches.

Project aim #3: Make clear comparisons with emissions from other activities (heating homes, eating meat, etc) and average total per capita emissions (UK, US, world and Africa).

Finding accurate information about the carbon impact of consumers' choices is not straightforward. At one time, numerous online calculators, including Defra's 'Act on CO_2' tool, were available to estimate an individual's personal 'carbon footprint'. But information is now not generally presented in terms of an average consumer, and the UK in any case has one of the widest ranges of carbon footprints in the EU[7] - a reminder that average figures need to be treated with some caution.

Nevertheless, it is helpful to consider the relative impact of flying compared with day-to-day activities, particularly those that people generally understand to have high climate impacts.

A 2019 report from the Energy Systems Catapult (a body set up with Government innovation funding to "accelerate the transformation of the UK's energy system") considers the current emissions from a typical UK household and what changes would be needed to achieve net zero emissions, and this analysis provides some useful data.

10:10 also published work[8] recently that compares emissions from various activities, and is a useful check on the figures we have found.

Emissions saving tCO2e	Up to 0.25	0.26 to 0.5	0.51 to 0.75	0.76 to 1	1.1 to 1.25	1.26 to 1.5	1.51 to 1.75
Go car free							❍
Recycle all household waste		❍					
Switch to a green energy supplier	❍						
Take one less transatlantic flight							❍
Go vegetarian/vegan for a year				❍			
Upgrade to energy efficient lightbulbs	❍						
Compost food waste	❍						
Reduce water usage	❍						

Source 10:10 (2019)

Food

On 1st May this year the Vegan Society launched its FlyVe campaign calling on airlines to offer vegan meals as a contribution towards carbon emissions. "Animal agriculture produces around a fifth of all man-made greenhouse gas emissions and meat, egg and dairy production is a bigger contributor to global warming than all forms of transportation combined, including aviation", the organisation argues[9]. Several key reports have highlighted the importance of diet to tackling climate change, including the claim in

[7] https://iopscience.iop.org/article/10.1088/1748-9326/aa6da9
[8] http://files.1010global.org/documents/Aviation_briefing_Jan2019_FINAL.pdf
[9] https://www.vegansociety.com/whats-new/news/airlines-urged-%E2%80%98fly-ahead-curve%E2%80%99-providing-vegan-options

2018 that avoiding meat and dairy "is the single biggest way to reduce your environmental impact on the planet"[10].

Globally, around a quarter of emissions come from food[11] and only around 2%[12] (of CO_2) from aviation. But while everyone must eat, only a small percentage of the global population flies and at an individual level, the impact of flying can be greater than that of a high-carbon diet.

The Carbon Independent website[13] collates a range of figures, with sources, for UK per capita emissions from diet. The site's own estimate is higher than any other source quoted at 2.2 tonnes per person per annum. Catapult estimates 1.6 tonnes per household based on an allocation to households of UK agricultural emissions (ie on a 'production' rather than a 'consumption' basis), which translates to just 0.7 tonnes per person on average, assuming the ONS average of 2.4 people per household.

In terms of the value of shifting to a vegan diet, a 2014 academic study[14] found that food-related emissions in kg CO_2e per day in the UK, assuming a 2000 calorie diet, were as follows. Actual calorie consumption is typically higher in fact[15] so annual figures seem likely to be underestimates. In the chart below, we have converted these figures to tonnes per annum by multiplying by 365 and dividing by 1000.

	Kg CO_2e/day	Tonnes CO_2e per annum
high meat-eaters	7.19	2.62435
medium meat-eaters	5.63	2.05495
low meat-eaters	4.67	1.70455
fish-eaters	3.91	1.42715
vegetarians	3.81	1.39065
vegans	2.89	1.05485

This supports the finding of a more recent study[16] reported by the BBC[17], which estimated that more than half of food emissions are associated with animal products.

Switching from a high meat diet to veganism, the biggest possible change, would save around 1.57tCO_2 annually for one person based on the figures from the Scarborough et al study. Switching from a medium meat diet to being vegan would save around 1 tonne CO_2e, meaning that taking a single long haul return flight that year could more than wipe out all the savings made through dietary change (see the final column, final section of Figure 1).

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[10] https://www.theguardian.com/environment/2018/may/31/avoiding-meat-and-dairy-is-single-biggest-way-to-reduce-your-impact-on-earth
[11] https://www.bbc.co.uk/news/science-environment-46459714
[12] https://www.carbonbrief.org/corsia-un-plan-to-offset-growth-in-aviation-emissions-after-2020
[13] https://www.carbonindependent.org/
[14] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4372775/
[15] https://www.telegraph.co.uk/news/2018/02/19/fat-britain-average-person-eats-50-calories-realise/
[16] https://ora.ox.ac.uk/objects/uuid:b0b53649-5e93-4415-bf07-6b0b1227172f
[17] https://www.bbc.co.uk/news/science-environment-46459714

Annual average emissions per capita from driving

Most transport emissions in the UK are from passenger cars. We look at 3 sources for an estimate of annual driving emissions.

(i) The Energy Catapult report says "Between 1990 and 2017, emissions from UK surface transport have increased in absolute terms. Allowing for growth in the number of households, the average per household emissions fell from 2,952 to **2,376 kg CO_2e**." This translates to around **0.99 tonnes** per person.

(ii) In the UK as a whole 125.9 Mt CO_2e were from transport in 2017, with 69.6 Mt ie 55% generated by passenger cars[18]. Assuming 66 million in the population this would translate to an average of 1.9 tonnes per person from transport. 55% of this (the proportion from passenger cars, so comparable to the transport emissions attributable to households) would be around **1 tonne per capita from passenger vehicles**.

Activity		MtCO_2e
Transport		125.9
Aviation	Civil aviation (domestic, cruise)	1.1
	Civil aviation (domestic, landing and take off)	0.4
Road	Passenger cars	69.6
	Light duty vehicles	19.4
	Buses	3.4
	HGVs	20.8
	Mopeds and motorcycles	0.5
	Road vehicle LPG and biofuel use (all vehicles)	0.3
	Incidental lubricant combustion in road engines	0.2
	Urea use in abatement technology	0.1
Railways	Railways	2.0
	Railways – stationary combustion	0.0
Shipping	National navigation	5.3
	Incidental lubricant combustion in marine engines	0.0
	Fishing vessels	0.6
Other mobile	Military aircraft and shipping	1.6
	Aircraft support vehicles	0.6

(iii) CCC says "By using a more efficient petrol or diesel car, the average home could save 0.9 tonnes of CO_2 per year. A fully electric vehicle could save 2 tonnes per year."[19] Assuming the electricity is zero carbon, this translates to 0.8 tonnes CO_2 per person from petrol/diesel cars.

All 3 sources suggest that annual emissions per capita in the UK from driving are around 1tonne CO_2, or just below. Taking a single long-haul return flight could therefore generate more emissions than a year's worth of driving.

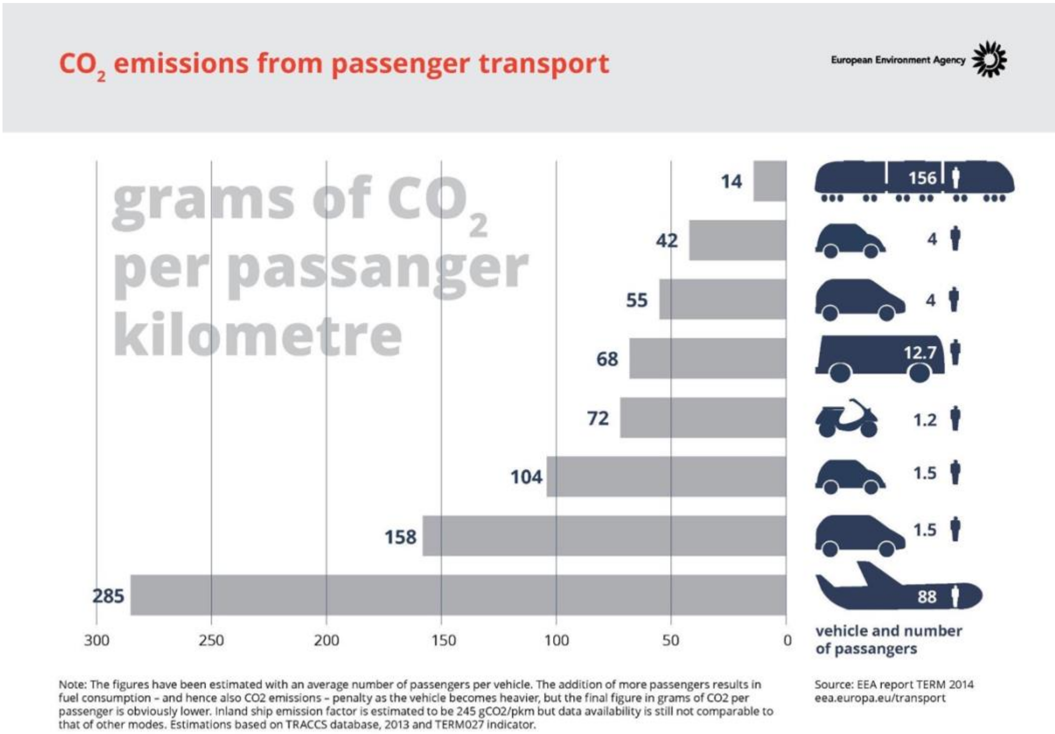
[18] https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2017
[19] https://www.theccc.org.uk/wp-content/uploads/2016/07/5CB-Infographic-FINAL-.pdf

An estimate of the emissions for a given journey made through different transport modes can be made by using the BEIS conversion factors referred to above. For a journey from London to Paris, for illustration, the following estimates can be derived from these figures.

London-Paris	km	kgCO_2/passenger km	Total CO_2 in kg
Rail - international rail	342[20]	0.00592	2.0
Flight (business class short haul 'no RF')	344[21]	0.12233	42.1
Flight (business class short haul with RF)	344	0.23243	80.0
Flight (economy, short haul, 'no RF')	344	0.08155	28.1
Flight (economy, short haul, with RF)	344	0.15495	53.3
Average petrol car one person	456	0.18014	82.1
Average petrol car 2 people	456	0.18014	41.1

An EEA graphic from 2014, meanwhile, neatly illustrates their estimate of the emissions of various transport modes per km.

[20] https://www.thetrainline.com/en/train-times/london-to-paris
[21] https://www.distancecalculator.net/from-london-to-paris



Household appliances

A tumble drier, according to the Carbon Footprint website[22], generates 0.16 kg CO_2 per annum.

Energy Catapult reports that: "In per household terms, the average emissions from heating fell from 4,535 to **2,745** kg CO_2e from 1990 to 2017." Assuming 2.4 people per household, this represents an average of 1.14 tCO_2 per person from home heating in 2017.

Per capita

Estimated average per capita emissions (based on territorial sources so excluding international aviation) can be found at Our World in Data[23]. In 2017, this shows per capita emissions for UK citizens to be 5.81 tCO_2, for the US 16.24tCO_2, and for China and India 6.98tCO_2 and 1.84tCO_2 respectively. Per capita emissions in Nigeria are 0.56tCO_2.

Carbon Brief estimates that average emissions are now as low as 5.4 tonnes per person in the UK, excluding international flights. Allowing for the extra emissions from UK international aviation would increase this to around 6 tonnes.

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[22] https://www.carbonfootprint.com/energyconsumption.html
[23] https://ourworldindata.org/grapher/co-emissions-per-capita

Discussion

Based on the results in Figure 1 and the information presented in Project Aim #3, it is possible to highlight the magnitude of aviation emissions compared with emissions from other activities and per capita emissions. Some examples are:

- Taking a single long haul return flight from Birmingham to Delhi (emitting just over 1 tonne CO_2 adjusted for additional climate impacts) would wipe out all the savings made by switching from moderate meat consumption to being vegan for a year.
- Annual emissions per capita in the UK from driving are around 1tonne CO_2, equivalent to the emissions of a single long haul return flight.
- Flying economy from London to Paris generates 27 times the CO_2 emissions of making the same journey by Eurostar (53 kg compared with 2 kg for a one-way trip)
- One return flight between Manchester and Southampton generates more emissions than running a tumble drier for a year (0.18 tonnes).
- A return business class flight between the UK and Delhi generates more emissions (at just over 2 tonnes) than the annual average emissions per capita in India (1.8 tonnes).

The figures set out above are all based on credible sources that are freely available in the public domain. For further detail and/or validation of these figures directly from experts, possible people to approach would be:

- Wynes and Nicholas, authors of this study, which was widely reported: https://www.theguardian.com/environment/2017/jul/12/want-to-fight-climate-change-have-fewer-children
- 10:10
- Mike Berners-Lee, author of *How Bad are Bananas: the carbon footprint of everything*. This was published in 2010, though we understand that the author has been working on an updated edition.
- Dr Tara Garnett, expert in food and emissions: https://www.oxfordmartin.ox.ac.uk/people/dr-tara-garnett/

Project aim #4: Clarify the carbon emissions per passenger for take-off, cruising (per thousand kilometres) and descent respectively for different sizes and types of aeroplane.

Why are emissions from short haul flights typically higher per passenger km than long-haul?

During a flight, aircraft will use different levels of engine thrust for the take-off, climb, cruise and landing phases. Take-off is at maximum power, and the least amount of thrust is used for landing. But because aircraft spend the largest proportion of a flight in the cruise phase, commercial aircraft are usually designed for optimum performance at their cruise speed. Short-haul flights will spend a much shorter proportion of the flight duration at cruise so the overall efficiency per passenger kilometre is usually less compared to long-haul.

Does the choice of airline make a difference?

Airlines have different average fleet ages. These are constantly changing as new aircraft are acquired while older models are retired. Also, airlines often configure their aircraft with different layouts, so the same aircraft can have different maximum seating capacities. For example, a low-cost carrier will have more seats available than a carrier that opts to offer premium class seats as well. This affects the overall efficiency of the aircraft. These differences aren't necessarily apparent from the results in Figure 1 as the calculations are usually performed using data that averages the performance of all aircraft and carriers operating on a given route.

US-based organisation ICCT (the International Council for Clean Transportation) produces an efficiency ranking for carriers operating on transatlantic routes. The latest ranking[24] is based on 2017 data.

ICCT estimates that the gap between the most and least fuel-efficient transatlantic airlines is 63%, with Norwegian Air Shuttle ranked top with an average fuel efficiency of 44 passenger-kilometres per litre of fuel (pax-km/L), 33% better than the industry average. British Airways ranks as the least fuel-efficient, at 22% below the industry average. Aircraft fuel burn and seating density are the most important factors in explaining the variation.

At present, consumers and travel companies have little or no information about the relative environmental performance of carriers or aircraft.

Does the choice of aircraft make a difference?

Emissions per passenger are also influenced by the type and age of aircraft flown. Using EuroControl's 'small emitter's tool' (developed to help operators report their emissions for the purposes of compliance with the EU ETS) it's possible to show the differences in fuel burn over selected distances. These are shown in the table below.

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[24] https://theicct.org/publications/transatlantic-airline-fuel-efficiency-ranking-2017

Aircraft:	Date of entry into service	Total fuel consumption by an aircraft flying 1500km in kg	Total fuel consumption by an aircraft flying 7000km in kg
Airbus A320-neo	2014	3,984	-
Boeing 737-800	1994	5,424	-
Airbus A330-300	1994	-	48,294
Boeing 787-900	2010	-	44,070

Project aim #5: Calculate the extra emissions from First Class over other premium classes

Seating class affects per passenger emissions, as premium seats – premium economy, business and first – weigh more, or, more importantly, occupy a greater percentage of the available floorspace than an all-economy layout. The ICAO carbon calculator methodology applies a simplified correction factor for premium seats, multiplying all premium seats by a factor of two compared to economy, on flights of more than 3,000km.

In 2013, the World Bank reported on *Calculating the Carbon Footprint from Different Classes of Air Travel*[25] . This detailed analysis of load factors and the space occupied in each seat class led the authors to conclude that the differences between classes can be significant (see table below). For load factors of 60% and 90% (the global average is around 83%), the emissions associated with business class seats are approximately twice that of an economy seat for both wide-bodied and single-aisle passenger aircraft.

Average footprints by travel class, relative to averages across classes, as functions of load factors

		Widebody aircraft			Single aisle aircraft		
	Load factor	30%	60%	90%	30%	60%	90%
Class type	Economy	1.92	0.96	0.64	2.06	1.03	0.69
	Business	4.38	2.19	1.46	3.88	1.94	1.29
	First	8.96	4.34	2.90	6.01	3.01	2.00

Source: World Bank (2013)

First class seats had an impact around four times that of an economy class seat on a wide-bodied jet, and about three times for a single-aisle aircraft. Given that most single-aisle aircraft operate on short-haul routes where first class is generally not offered, it would be reasonable to base a calculation for first class on wide-bodied aircraft only. Based on the World Bank analysis there is evidence to support using a simplified multiplier for seating class relative to economy, of 2 for business class and 4 for first class.

MyClimate and Atmosfair use weightings factors that are generally equivalent to factors of 2 for Business and 3 for First class, but their exact calculations vary by route and aircraft type. The BEIS reporting factors mentioned earlier, also distinguish between seat class. These state that premium economy is times about 1.6 times greater than economy, while business and first class are 3 times and 4 times respectively for long-haul travel.

To present information to a public audience in a simple way, we suggest using the following formula: Economy class 1, premium economy 1.5, business 2 and first class 4.

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[25] http://documents.worldbank.org/curated/en/141851468168853188/pdf/WPS6471.pdf