The Climate Impact of Passenger Transport: Cars, Trains, and Planes

Kilian Bartsch*

The carbon footprint was born as a public relations tool of the oil industry.[1] Determining individual impact should not demoralise or paralyze but rather accompany bigger institutional changes in our organisations and countries, similarly to the labelling of calories on restaurant menus; the first objective should not be to shame, but to inform. In the calories example, the predominant change does not come from the conscious consumers, but rather from the chefs (or policymakers) who adapt the offering.[2] In this article, the climate impact of travelling by car, train and airplane will be quantified and explained. This will be contextualised in terms of an understandable and relatable metric: the reduction targets per person per month from the UK's carbon budgets.

I. Cars: Electric vs Combustion.

Electric cars have a lower climate impact than combustion equivalents. The small additional battery manufacturing emissions and associated material extraction only slightly decreases the lifetime benefits of electrifying.[3] For a medium average UK car in 2023, a petrol vehicle emits 228 gCO_{2eq}/km travelled, whereas a battery electric equivalent emits 64 gCO_{2eq}/km.[4] Another useful metric in the car context is the distance or duration needed to be driven to tip the lifetime emissions in favour of the electric car. For a battery produced in China driven for ever on the electricity produced in 2022, this would be 48,000km in the UK or 37,000km in France[5] (or 2-3 years of driving of the author's parent's car). After that turning point, every additional kilometre has an even greater impact differential. Importantly, the emissions associated with operating an electric car decrease every year more renewable electricity generation is built (UK 2010 485, 2019 270 gCO_{2eq}/kWh[6]), while the carbon efficiency of the combustion car is frozen for its life.

To fairly compare two cars over their lifetime, choosing similar capability and technology (year of manufacture) is important. When considering modes of transport that are purchased per journey, or when considering the transport needs of a whole country, comparisons are based on passenger-kilometres (pkm) transported (3 passengers travelling 50 km is 150 pkm).

II. Rail Climate Impact.

Trains have a substantially lower climate impact than combustion engine cars and flights on equivalent journeys. The difference can be broken down in terms of operational advantage and electrification. The

---

* **PhD Candidate (Aeronautical Engineering), Darwin College, University of Cambridge**

[1] Kaufman, Mark. "The Carbon Footprint Sham." *Mashable*.

[2] Rutherford, Dan. "Science-Based Aviation Regulation." *Aerospace Ambition*, Episode 17, 19 April 2024.

[3] Jolly, Jasper. "EV Mythbusters: Do Electric Cars Really Produce Fewer Carbon Emissions than Petrol or Diesel Vehicles?" *The Guardian*, 23 Dec. 2023.

[4] DESNZ. "Greenhouse Gas Conversion Factors 2023: Full Set", 28 June 2023.

[5] Miotti, Marco, et al. "Personal Vehicles Evaluated against Climate Change Mitigation Targets." *CarbonCounter*, 27 Sept. 2016.

[6] Ritchie, Hannah, et al. "Data Page: Carbon intensity of electricity generation", *Our World in Data,* 2023. *see* 2022 values for China: 534, UK: 261, France: 85 gCO_{2eq}/kWh.

operational advantage of a diesel train over petrol cars comes from multiple factors that are hard to disentangle: higher occupancy (UK cars have 1.6 passengers on average),[7] less acceleration, and bigger engines. Electrification provides a further climate advantage as large fractions of the electricity are produced from non-fossil sources. Not all tracks are electrified: the numbers differ even in Western European countries (38% in the UK, 74% in the Netherlands, 100% of France's high-speed network and 66% of the remaining French network), but as the busiest lines are most economical to electrify, a high fraction of journeys occur on electrified tracks (72% of 2019 carriage-km in the UK).[8] The main reason why certain tracks are not yet electrified is due to high upfront costs and longer returns due to low usage. Certain countries have clear electrification goals and progress like Germany and France, progress in the UK has been more sporadic.

The following figure on train travel shows the emissions per passenger kilometre of a selection of European trains in 2019, adjusted from national and company reports to a consistent set of electricity production emissions. The main takeaway is that combustion cars emit more than diesel trains, and diesel trains have a larger climate impact than electric equivalents – even in countries with high carbon intensity of electricity like the Netherlands (2019 average: 455 gCO_{2eq}/kWh[9]).

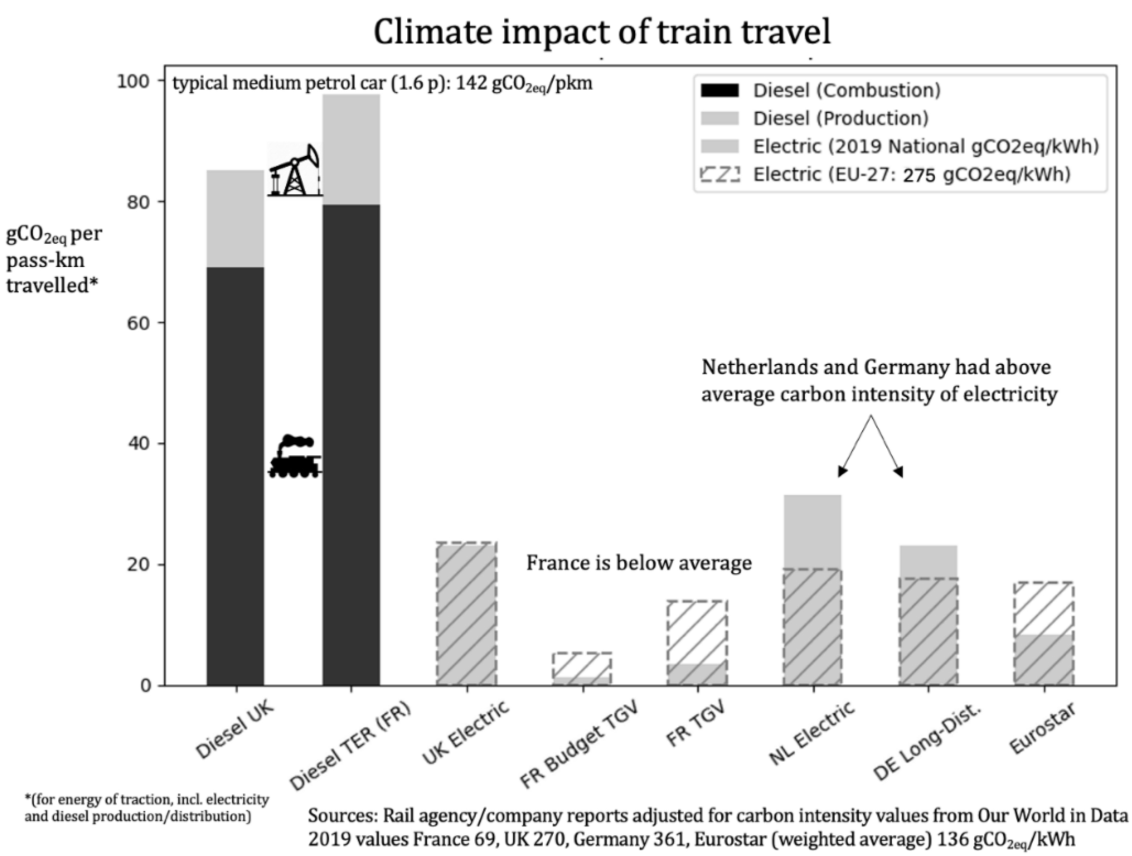

Figure 1: Climate Impact of Traction Energy for a Selection of European Trains.

---

[7] Department for Transport. "Transport Statistics Great Britain: 2019 Tables." 17 Dec. 2019.
[8] Office of Rail and Road. "Rail Emissions Data Tables." 14 Nov. 2023.
[9] Richie, Hannah et al. (n 6) *supra*.

The differences between trains using the same fuel can be attributed to different seat densities and load factors (the average number of passengers per seat). For example: TGVs have two floors, packing more seats per length of train than single deck Eurostar or German High-Speed trains. The French TGV OUIGO, a budget equivalent to the normal TGV INOUI, achieves even higher seat densities.

Rail companies can be the biggest single electricity consumer in the country. In climate conscious countries with carbon intense electricity, they therefore buy renewable power purchase agreements (PPA). PPAs lead to operators in Germany, Netherlands, and Eurostar to boast lower emissions than depicted (the French do so by using a lower factor for nuclear electricity than global averages).

When considering rail from a long-term policy perspective, infrastructure emissions also become relevant: just like roads, the construction of train tracks result in significant climate impact. Several studies have attempted to quantify the impact: it depends on the number of tunnels and bridges, but bringing it back to a value per pkm also greatly depends on the lifetime of the tracks and the number of trains/passengers that use it.[10] Busy, well-maintained train tracks are very much worth the climate investment. A detailed analysis of a section of French high-speed rail found that the up-front impact was compensated by the passengers now travelling by train that would have used a car/plane after 12 years[11] (well-maintained tracks can be used for well over 50 years). Finally, the tracks and roads may also be used by freight transport, which must be accounted for when fully attributing the climate impact.

III. Aviation Climate Impact.

Airplanes have a large climate impact for the same reason why aviation has made the world smaller: large distances can be covered quickly. This is not captured when normalising per kilometre. Many of the carbon calculators that allow journey-to-journey comparisons use an average emission factor for air travel:[12] distinguishing between short-, medium- and long-haul flights at arbitrary cut-offs. Typical values for economy flights from the UK are 194 (domestic), 130 (short haul) and 143 gCO_{2eq}/pkm (long haul).[13]

The main variation within these categories is due to the aircraft (engine) type and age, how dense or luxurious the seating arrangement is, how full the seats are, how much cargo is being carried, and how far the aircraft is being flown. For the B787-8, a modern long-haul aircraft that entered service in 2011 and accounts for about 10% of long-haul travel to and from the UK, Figure 2 shows the trends of these dependencies.

At very short ranges, the B787-8 needs a large fraction of fuel and emissions to reach cruising altitude (Climb), whereas at long ranges, the aircraft must carry enough fuel to finish the flight, increasing the average weight (Tankering). Budget airlines put more seats in the same aircraft, achieving lower per

---

[10] International Union of Railways. "Carbon Footprint of Railway Infrastructure." 12 July 2016.

[11] SNCF, ADEME, RFF. "La Ligne à Grande Vitesse Rhin-Rhône au Service d'une Europe Durable: Life Cycle Assessment of the Rhin-Rhone High Speed Track." 2011.

[12] Pellas, Chiara et al. "Lowtrip, a Web App to Compute CO_{2eq} for Different Modes of Transportation Worldwide." Mar. 2024; ADEME, "Base Empreinte", 2024.

[13] DESNZ (n 4) *supra*.

passenger-km impact, but are the source of most of the growth and the consequent increase in total climate impact of the sector. In the years following the pandemic, flying behaviours substantially changed, making it harder for airlines to predict demand or fill seats by managing prices; this resulted in occupancy rates or load factors below 60% (compared to pre-pandemic and 2023 values exceeding 80%).

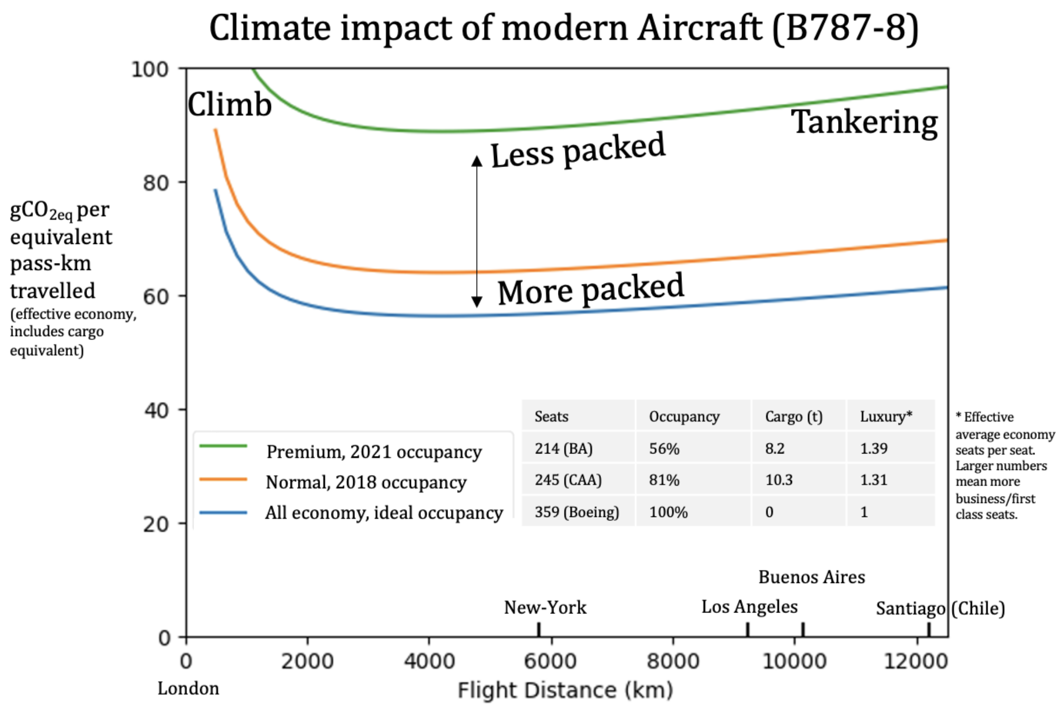

Figure 2: Climate Impact of Modern Long-Haul Aircraft.

Contrails, the long white condensation trails seen in the sky, have intentionally not been included in the previous numbers and figure. Their climate impact is very large and estimated to be of the same magnitude as all other climate impacts of aviation—and should further increase the urgency to minimise distance flown. However, less than 5% of flights cause >90% of the impact from warming contrails.[14] Regulators, airlines, and operators are already planning how to avoid these harmful contrails, and in the coming years there will hopefully be adequate management to address a rapid decrease in this short-lived climate forcer. Unlike CO_2, which stays in the atmosphere for centuries, contrails last less than a day, which means that when we stop flying or fly without producing them, the consequence on the climate is felt immediately. It is therefore a rapid method to achieve a reduction in warming (like reducing methane leaks).

The most accurate public carbon calculator for airplanes' CO_{2eq} impact is the Travel Impact Model,[15] which is behind the estimates of many online booking platforms. Global contrail coverage can be seen in

[14] Teoh, Roger, et al. "Global Aviation Climate Effects from 2019 to 2021", *EGU-Sphere Pre-Print*, 10 Oct. 2023.
[15] Rutherford, Dan. "Flight Emissions Calculator." *Travel Impact Model*.

near real-time on a Breakthrough Energy's contrail map and can be reported via their accompanying mobile application.[16]

IV. Understanding CO2 Equivalents in the Context of UK's Carbon Budgets.

Climate impact and kilograms of CO_{2eq} can be contextualised in terms of numbers of trees planted or compared to the emissions of another activity like a flight between London or Paris and New York. The UK's pioneering carbon budgets on a per person per month basis can provide a new lens through which to understand kg CO_{2eq}. In the figure below the UK's historical emissions are presented per inhabitant.[17] In the most recently legislated budget for 2035, international aviation and shipping (as measured by UK refuelling) has been included for the first time.[18] The next step will be to include embedded emissions from imports consumed in the UK.[19]

The reductions to date have primarily come from transitioning from coal electricity production to gas, and more recently from the expansion of offshore wind energy. Further reductions will be achieved by expanding renewable electricity production and transmission. But as future reductions will involve increasingly active participation of individuals, the framing in terms of a monthly emission budget can help to inform decisions. 5 years to reduce by 300 kg CO_{2eq} and 15 years to reduce by a further 300 kg CO_{2eq} can be mapped to personal decisions like buying an electric car, hob, or heat pump, eating less meat or dairy, or installing solar panels.

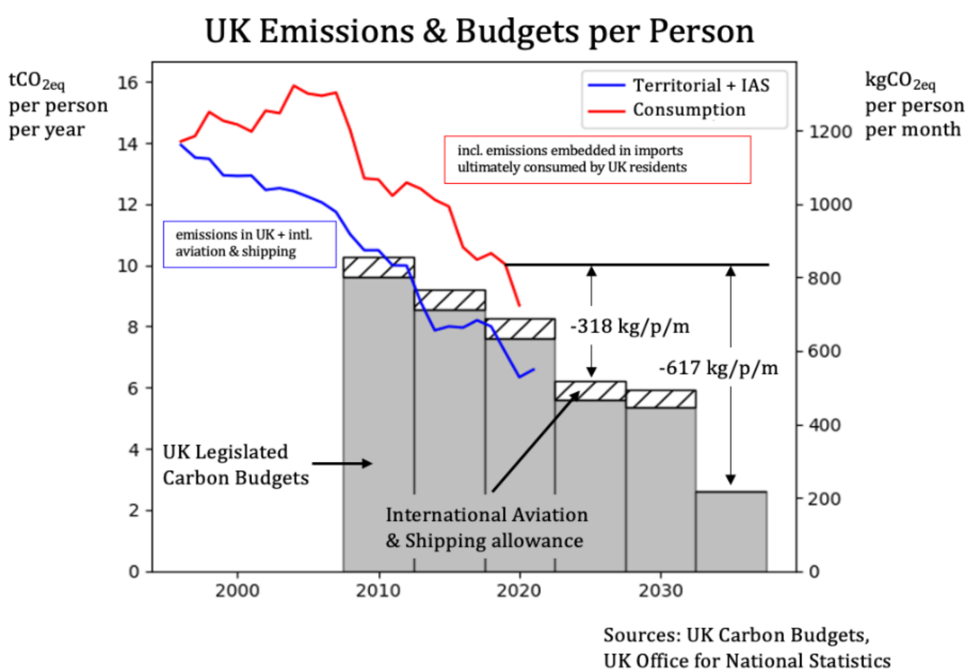

Figure 3: UK Carbon Budgets and Historical Emissions per Person.

[16] Reviate. "Contrail Map" *Breakthrough Energy*. *see* the 'Contrails Observer' mobile application.
[17] DESNZ, BEIS. "UK Territorial Greenhouse Gas Emissions National Statistics." 28 Mar. 2024.
[18] UK Government. "UK Enshrines New Target in Law to Slash Emissions by 78% by 2035", 20 Apr. 2021.
[19] DEFRA. "Carbon Footprint for the UK and England to 2020" 19 Jan. 2024.

In terms of transport, some quantified orders of magnitude are given as examples: long distance or regular trips have the most reduction potential. Replacing three return flights per year between London and Munich would change the average climate impact by -40 $kgCO_{2eq}$/month. Going only once every two years to Chicago would amount to -44 kg/m or replacing it entirely with a yearly trip to Dublin -78 kg/m. Rather than driving 240 days a year 2x15 km to work and back, using an electric car would bring -98 kg/m, or an electric bike -130 kg/m.[20] Working from home 2 days per week would be -55 kg/m.

V. Conclusion.

Transport is a major contributor to global warming, and one where the emissions are very tangible and easy to quantify. As the climate crisis worsens, our habits of how we move around are going to change, by choice or legislated incentives. A quantified understanding of the differences between different transport modes coupled with a clear reduction guideline can help guide individual choices and policy. The macroeconomic UK carbon budgets were brought down to an average monthly budget per person, which can be useful to contextualise the results of any microeconomic carbon footprint estimation and decisions. From a baseline (including embedded emissions in imports) of 836 $kgCO_{2eq}$ per person per month in 2019, average reductions of 318 $kgCO_{2eq}$/p/m are needed to meet the budget of 2025 and a further 299 $kgCO_{2eq}$/p/m for the budget of 2035.

[20] Using 11 gCO_{2eq}/km for an electric bike, including manufacture, from the ADEME database.