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Rank-order concordance among conflicting emissions estimates for informing flight choice

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ABSTRACT

Air transport Greenhouse Gas (GHG) emissions estimates differ greatly, depending on the calculation method employed. Among the IPCC, ICAO, DEFRA, and BrighterPlanet calculation methods, the largest estimate may be up to 4.5 times larger than the smallest. Such heterogeneity – and ambiguity over the true estimate – confuses the consumer, undermining the credibility of emissions estimates in general. Consequently, GHG emissions estimates do not currently appear on the front page of flight search-engine results. Even where there are differences between alternative flights' emissions, this information is unavailable to consumers at the point of choice. When external considerations rule out alternative travel-modes, the *relative ranking* of flight options' GHG emissions is sufficient to inform consumers' decision making. Whereas widespread agreement on a gold standard remains elusive, the present study shows that the principal GHG emissions calculation methods produce consistent rankings *within specific route-structure classes*. Hence, for many consumers, the flight identified as most GHG efficient is not sensitive to the specific calculation method employed. But unless GHG emissions information is displayed at the point of decision, it cannot enter into consumers' decision making. A credible and ambiguity-free alternative would thus be to display GHG *ranking* information on the front page of flight search-engine results.

1. Introduction

At the point of decision, consumers are generally not provided with the GHG emissions information required to make an environmentally responsible choice between different flight options. Flight search engines typically display GHG information, if at all, on CO_{2e}-offset pages which are reached after a specific flight has been selected for purchase. Given differences between emissions calculation methods and differing views on Radiative Forcing (RF), any one CO_{2e} calculator confers advantage to some flights and disadvantage to others in a manner that, to an airline company, may appear arbitrary and unwelcome. For competitive reasons, airlines have been reluctant to elevate GHG emissions to be front-page product-defining attributes alongside price and convenience. Multiple-methods, multiple-estimates ambiguity is a major impediment to the promotion of CO_{2e} to the front page of flight search-engine results, where it must appear in order to have an impact upon consumers' choices.[1]

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[1] We thank one of our anonymous Reviewers for pointing out that some airlines do make attempts to communicate flights' emissions to customers, through e.g. eco-labeling schemes or in connection with carbon off-setting schemes. However, this falls short of appearing on the front page of search-results screens – i.e. at the point of decision – of flight-search engines which aggregate across airlines and airline alliances.

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In this study we document the degree of heterogeneity in the estimated emission *levels* calculated with different methods. We then investigate the linear association between and *rank-order* concordance among different methods' estimates. We do so both through examining the calculation methods' formulae as well as through statistical analysis of flight data, including a broad, representative global sample drawn from IATA's World Air Transport Statistics.

In Section 2 we review previous research on flight-level GHG emissions estimates, and in Section 3 we discuss four calculation methods in detail: DEFRA, ICAO, BrighterPlanet, and EEA/IPCC. In Section 4 we report statistical analysis and testing of linear association between – and rank-order concordance among – the different methods. Section 5 concludes.

2. Previous research

Civil aviation GHG emissions are estimated as global-level inventories (Olivier, 1995; IPCC, 1999; Wilkerson et al., 2010; Simone et al., 2013; Wasiuk et al., 2015), regional-level inventories (Wasiuk et al., 2015), national-level inventories (Pejovic et al., 2008; GAO, 2009), airport-level inventories (Hudda et al., 2014; Sherry, 2015), airline-level inventories (Miyoshi and Mason, 2009; van Dorland et al., 2009; Zou et al., 2012), and as performance statistics for individual engines or aircraft (Green, 2002; DuBois and Paynter, 2006). At each of these levels there is a well-defined clientele for these emissions-estimate data, and hence there is a substantial volume of research being continually conducted and published on all of these levels. Within tourism research, emissions-offsetting schemes and the GHG-emissions calculators they employ have been investigated by a variety of authors, including e.g. Gössling et al. (2007). Other strands of literature examine consumers' understanding of transportation CO_2 information when, as is typically the case, it is presented in mass units (Coulter et al., 2007), as well as the effectiveness of different contextualization and 'nudge' devices for enhancing the behavioral impact of transport CO_2 information (Waygood et al., 2012; Avineri and Waygood, 2013). For numerous reasons – participation in a regional emissions-trading scheme (e.g. the EU Emissions-Trading Scheme), meeting carbon-reduction targets, and the study of transport-mode choice for informing transport policy – GHG emissions have become the subject of a vast volume of transport research.

In stark contrast, research on flight-level GHG emissions-calculation methods – for informing consumers at the point-of-choice – is exceptionally sparse. Moreover, this research remains within the gray literature (institutional reports), despite point-of-choice GHG-emissions calculation being the necessary input for making environmentally responsible decisions when purchasing flights through flight-search engines, and despite the transport-research field recognizing point-of-choice influence as being an environmentally consequential and legitimate research question in its own right (see e.g. Avineri and Waygood, 2013).

These gray-literature studies originate from the Stockholm Environment Institute (Kollmuss and Lane, 2008; Kollmuss and Myers Crimmins, 2009), the Oxford Environmental Change Institute (Jardine, 2009), and the Breda Centre for Sustainable Tourism & Transport (Eijgelaar et al., 2013). Common to these studies is the aim to identify the best calculation method, if such an optimal method exists and is discernible as such. The calculators – and the studies at least in part – are motivated by GHG-emissions off-setting systems' requirements for such estimates, by GHG-emissions accounting and reporting requirements, and by teleological reasoning fixed on the objective of having travel-mode choices respond to flight-specific GHG emissions.

These studies document great differences between the flight-specific estimates provided by the existing GHG-emissions calculation methods. They conclude that, whereas different calculation methods have different advantages and strengths,[2] ultimately all of the calculation methods are imperfect and involve strong compromises.

Whereas we discuss the calculation methods in detail below (Section 3), here we note two sources of uncertainty emphasized in the gray-literature studies. First, aside from any inaccuracies in the raw input information regarding plane type and its engines, [3] actual emissions will deviate from calculated emissions because of (i) variation in climatic conditions, such as headwinds or tailwinds, (ii) variation in flight distances and paths, due e.g. to weather-related routing, (iii) variation in time spent in the holding-pattern 'stack', and (iv) variation in the mass of the aircraft from one flight to the next (Jardine, 2009). These sources of irreducible variation entail that there are limits to the precision with which realized GHG emissions may be estimated ex ante. Second, there are numerous metrics with which to adjust airliner CO_2 estimates to account for non-CO_2 effects[4]: Radiative Forcing (RF),[5] Radiative Forcing Index (RFI), Integrated Radiative Forcing (IRF), Global Warming Potential (GWP), Global Temperature Change Potential (GTP), and Integrated Change in Temperature over Time (ICTT) (Kollmuss and Myers Crimmins, 2009). The most commonly used adjustment metric is RFI, which is defined as the ratio of total RF to RF from CO_2 emissions alone. The RFI value used in some calculators may be as high as 4 (Jardine, 2009). However most pre-2005 implementations employed the IPCC (1999) report's central estimate of 2.7, and most post-2005 implementations employ Sausen et al.'s (2005) updating of the original IPCC estimate to 1.9.

[2] for instance some utilize extensive detailed information about the flight, whereas at the other extreme some methods employ simple, robust calculations with low informational requirements.

[3] Due to operational exigencies, airlines will occasionally substitute one aircraft with another that is not a precise match down to airframe model and variant, engine type, vintage and efficiency.

[4] emission of water vapor (H_2O), nitrogen oxides (NO_x), particulates (sulfates and soot aerosols), and the formation of contrails and cirrus clouds.

[5] The RF of a forcing agent (a gas) is the difference between incoming solar radiation and outgoing infrared radiation, expressed in Watts per square meter (W/m^2).