Comment

Supplementary information to:

An analysis of ways to decarbonize conference travel after COVID-19

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Supplementary Information
to the Nature Comment 'An analysis of ways to decarbonize conference travel after COVID-19'

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Data and Methods

Data are based on the abstracts of the scientific programme published by AGU, covering both oral and poster abstracts, downloaded on Nov 13, 2019. We identified the presenting author from all 26,133 abstracts. Of those, we geolocated the affiliations of 24,008 unique presenters, about 86% of all 28,000 attendees. For the total carbon footprint and the total distance travelled, we extrapolate the footprint of the 24,008 presenters onto all 28,000 attendees. A list of numbers of presenters can be found in Klöwer, 2019 (11), sorted by city and country or state in the US. The departure location per presenter is assumed to be their affiliation's city. We assume all journeys to be direct, such that they correspond to the great circle distance. Every attendee is assumed to travel back to their departure location with the same mode of transport.

Data for EGU attendees is published by EGU as number of attendees per country per year, downloaded on Apr 10, 2020 from their website and can also be found in Klöwer, 2019 (11).

Mode of transport and carbon emissions

The mode of transport is assumed given the distance to San Francisco. Table S1 summarizes the categories and associated assumed carbon emissions (12-20). Rail, car or bus is assumed for all journeys with distances of less than 400km, which includes departures from e.g. Sacramento but excludes Los Angeles. Airplanes are assumed for longer distances. The distinction between long-haul and super long-haul are geographically motivated: A super long-haul or intercontinental flight requires in most cases to cross either Pacific or Atlantic to get to San Francisco.

Mode of Transport	Distance to SFO [km]	Carbon emissions [gCO2e / km / person]
Rail, car or bus	<400	60
Short-haul flight	400-1,500	200
Long-haul flight	1,500-8,000	250
Super long-haul flight	>8,000	300

Table S1. Assumed mode of transport by distance to San Francisco (SFO) and associated carbon emissions.

For EGU, due to better rail-connections to Vienna, we assume distances of less than 700km to be travelled by train and reduce the emissions to 30gCO2e / km / person (13,14).

The carbon emissions per flight category take into account factors that typically decrease the per km emissions for flights such as (16-20)

- increased fuel consumption for take-off
- decreased detour factors for longer flights
- average aircraft types and their fuel consumption
- average passenger load factors for average airlines.

Additionally, we take into account factors that typically increase the per km emissions for longer flights, which on average tend to outweigh the factors from above (16-18,20)

- increased fuel weight for longer flights
- increased flight altitudes depending on distance covered
- indirect CO2 effects on ozone and cloud formation depending on flight altitude.

Some emission calculators do not include all of the factors above (17,18). To our knowledge, the atmosfair calculator (16) is the most sophisticated, but the results here can be replicated with other travel emission calculators too (17). The atmosfair calculator includes the indirect CO_2 effects not just as a factor 2, as an approximation recommended by Jungbluth and Meili, 2019 (21) but makes this factor flight altitude-dependent (as recommended as a next order accuracy therein). Additionally, atmosfair's calculator uses a database which analyses the aircraft types, their fuel consumption and passenger loads typically flown on specific routes. We therefore obtained our assumed emissions values by searching for typical flight routes to San Francisco and simplified the results. We assume economy class for every attendee.

We assume the same emission categories for Chicago, Tokyo and Paris although train travel in these regions will likely reduce the emissions of shorter journeys compared to San Francisco.

Carbon emissions of virtual conferences

The total server-to-consumer energy consumption of video-streaming from YouTube emits about 28gCO2e per hour (22), at a bandwidth of 1 Mbps and a significant share via cellular networks. Assuming a reduced bandwidth of 500kbps for scientific presentations compared to YouTube videos and mostly laptops connected to WiFi reduces the carbon intensity of video conferencing to 8gCO2e per hour. A fully virtual AGU Fall Meeting with 28,000 attendees video-conferencing for one week (9 hours a day) therefore emits about 10tCO2e, less than 0.1% of the travel emissions from 2019.

Sensitivity to assumptions

Sensitivity to the assumptions is fairly low. Main contributions to the uncertainty of the carbon footprint are:

a) **The carbon dioxide equivalent emissions of long-haul and super long-haul flights**. These are assumed to be 250g and 300g CO2e / km / person, respectively, which is a representative average. The emissions of individual flights have much higher uncertainty and depend on the number of passengers, airline / flight class, type of aircraft, potential detours, flight altitude, and weather conditions. The carbon dioxide equivalent emissions of super long-haul flights (>8,000km) are slightly higher per kilometer due to additional fuel weight and flight altitude, although increased fuel consumption from start and detour contribute less for such long distances.

b) **The exact route traveled by every attendee.** We have to assume great circle distances for every route traveled, although most attendees have to travel to the closest international airport first. Some routes require stopovers at airports that usually come with some detour. It is assumed that these detours rarely add more than 20% to the distance covered. As most attendees arrive from major cities with direct connections to San Francisco, we consider this uncertainty to contribute less than 10% to the total travel carbon footprint.

c) **The carbon dioxide equivalent emissions of rail, bus or car journeys.** These are assumed to be 60gCO_2e / km / person, which we estimate as an average, due to the lack of data on modes of transport. Emissions from individual journeys can, however, vary by an order of magnitude depending on the type of bus or car, type of train (electric, diesel, high-speed or regional), the local energy mix (for electric), number of passengers, detours relative to the shortest distance, etc. As the contribution of rail, bus or car journeys to the overall carbon footprint of AGU-related travel is negligible (<0.1%), the uncertainty here is negligible too.

Sensitivity to assumptions of the optimal locations

Analysing the optimal location for the AGU Fall Meeting assumes the same attendees as for the 2019 conference in San Francisco. Relocating comes with an additional pull factor of conferences that are held in vicinity of a scientist's location: The data from 2019 likely includes attendees from California that only attend because the conference is held nearby in San Francisco, but which wouldn't attend a conference in Chicago. Assuming their attendance therefore yields slightly higher total emissions, which results in a slightly larger reduction potential than 12% when relocated to Chicago. However, as most of the emissions come from long and super long-haul flights, we estimate this effect to have negligible influence on the exact location that minimizes the carbon emissions. The same holds for the three-hub conference model.

Data and materials availability All data is available in Klöwer, 2019 (11).

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Supplementary Figures

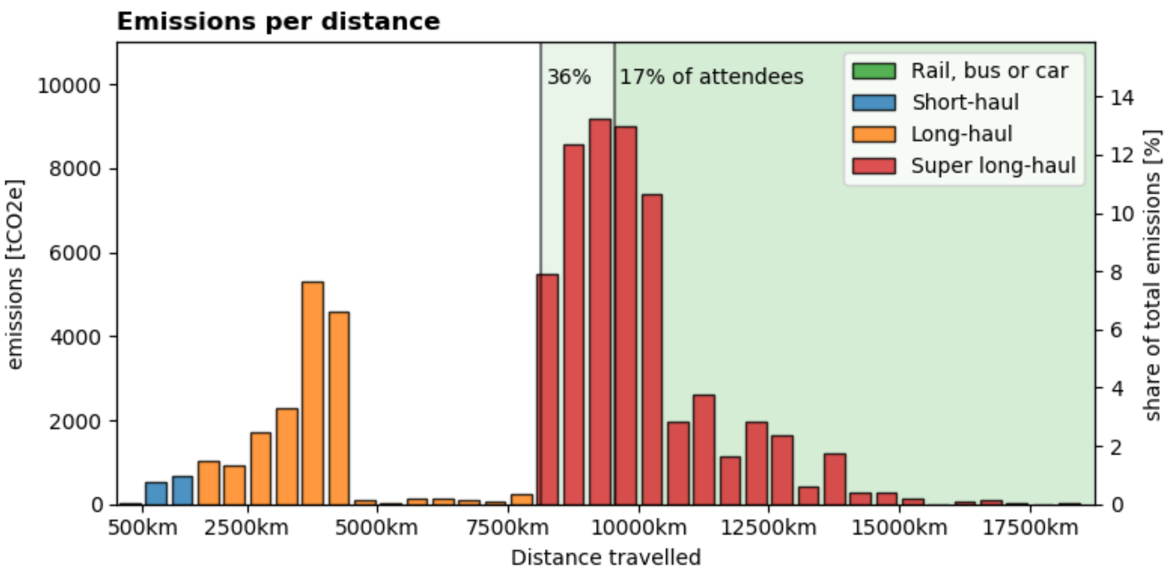

Fig. S1. Travel carbon emissions as a function of distance. The emissions are for retour journeys, whereas the distance is one-way. The distances of the highest 17% (more than 9540km away from San Francisco) and 36% (more than 8145km) emitting attendees are marked. Rail, bus or car journeys account for less than 0.1%, short-haul flights for 2%, long-haul flights for 24% and super long-haul flights for 74% of total emissions.

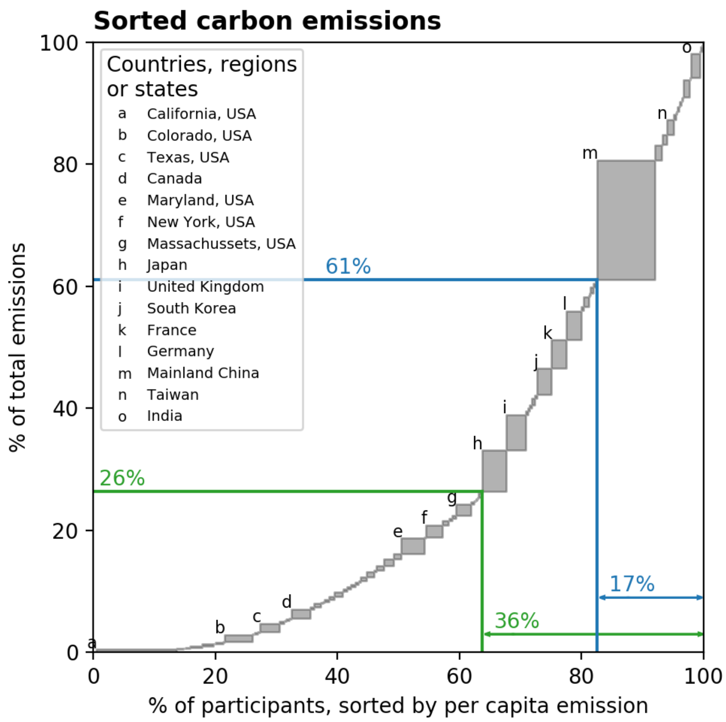

Fig. S2. Carbon emissions sorted by highest per capita emissions. Each grey rectangle represents one country or US state, some of the largest in terms of emissions or participants are named. The 36% furthest-travelling AGU attendees (green lines) are responsible for 74% of the conference's total travel carbon footprint, with the top 17% (blue lines) accounting for 39% of the total.

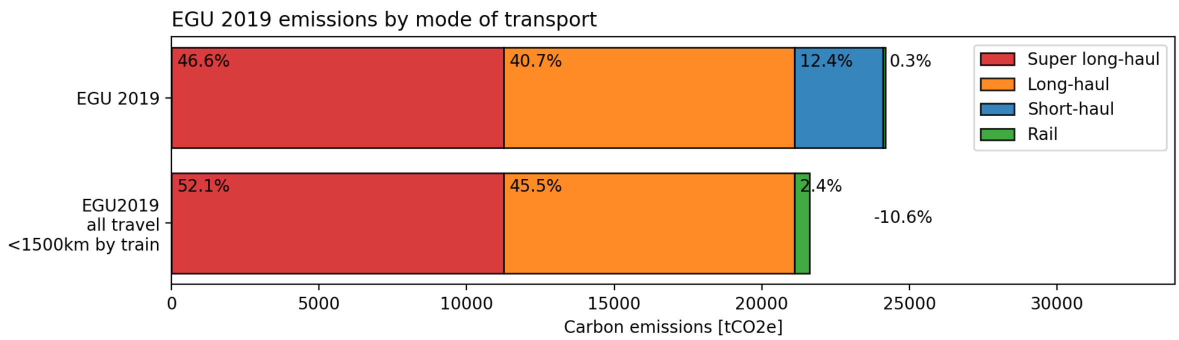

Fig. S3. EGU 2019 emissions by mode of transport. A scenario, in which all short-haul flights are replaced with rail journeys, decreases the carbon footprint by 10.6%.

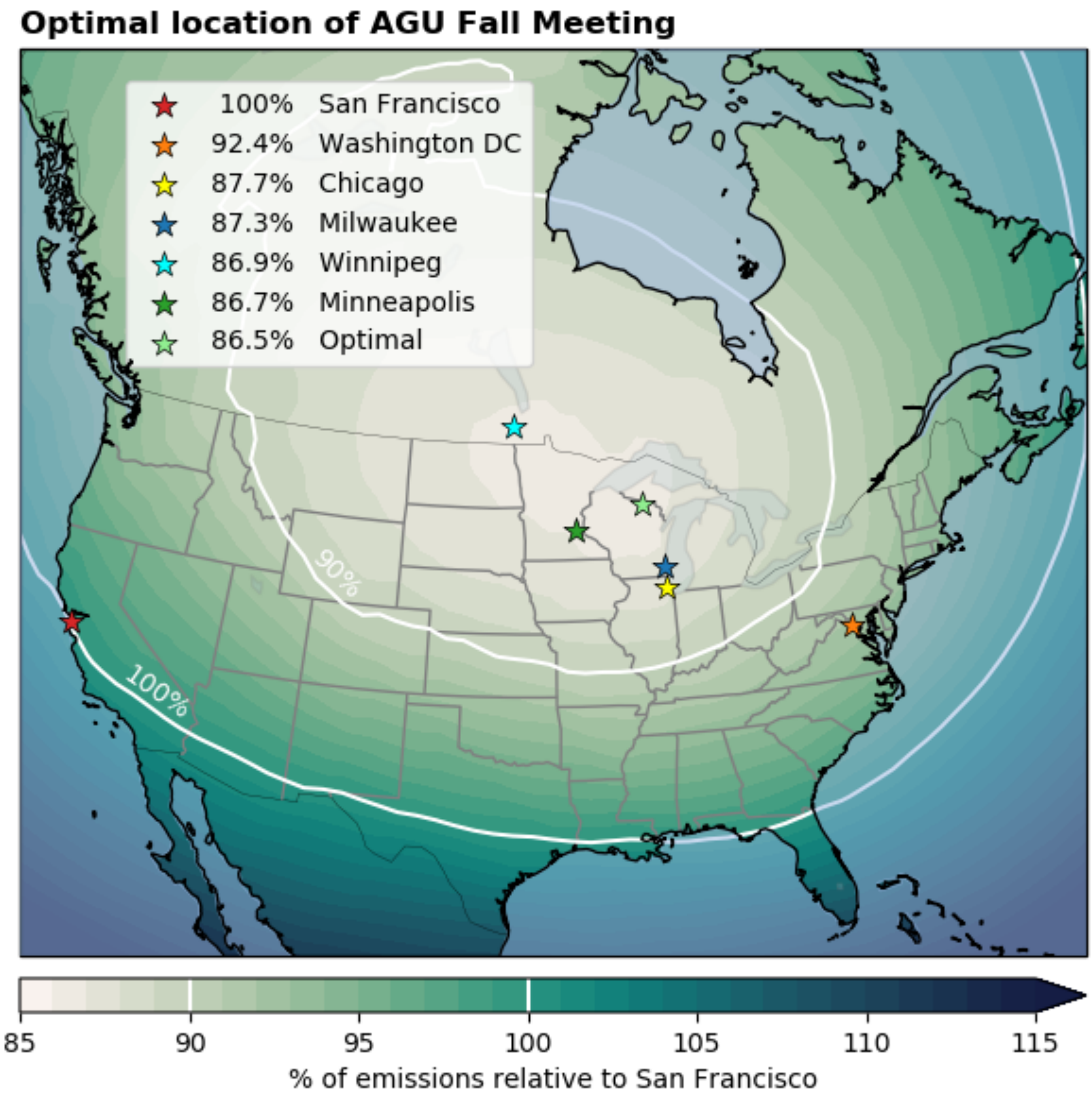

Fig. S4. The optimal location for the AGU Fall Meeting to minimize the total distance travelled. Optimal locations are shown in terms of the carbon emissions relative to San Francisco. White lines enclose areas where the emissions would be below 100% and 90%, as indicated. The optimal location is in northern Wisconsin. Chicago is reasonably close to the optimal location, reduces the emissions by 12%, and is internationally easily accessible.