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ABSTRACT

Purpose: To determine the airplane travel-related carbon footprint of the Radiological Society of North America (RSNA) annual meeting, the associated health burden, and the costs to offset these greenhouse gas emissions (i.e. compensation of emissions by funding an equivalent CO_2 saving elsewhere).
Methods: The RSNA's website was used to determine the reported country of origin of attendees to the 2017 meeting that took place in Chicago from November 26 to December 1. It was assumed that attendees had traveled from the airport nearest to the largest city in their country or state to Chicago's O'Hare international airport. The total amount of air travel-related CO_2-equivalent emission (based on round-trip economy class travel), the imposed health burden in terms of disability-adjusted life years (DALYs) in the global population, the total CO_2 offsets costs, and the CO_2 offsets costs per DALY were calculated.
Results: The calculated airplane travel-related CO_2-equivalent emissions of 11,223 attendees from the United States and 10,684 attendees from other countries were 7,067,618 kg and 32,438,420 kg, totaling 39,506,038 kg. This caused an estimated 51.4–79.0 DALYs. The calculated amount of Total CO_2 offset costs were calculated to be $474,072, which corresponds to $6,001–9,223 per DALY averted.
Conclusions: The airplane travel-related carbon footprint of the RSNA annual meeting and the associated disease burden are relevant, and potential attendees and organizers should take measures to overcome this undesired side effect. Offsetting this carbon footprint is cost-effective and this initiative should be taken by the radiological community.

1. Introduction

Climate change poses a serious threat to global health [1]. The direct effects of climate change include increased heat stress, floods, drought, and increased frequency of intense storms, with the indirect threatening of population health through adverse changes in air pollution, the spread of disease vectors, food insecurity and undernutrition, displacement, and mental ill health [1]. Restricting the global average temperature rise to less than 2 °C may avoid the risk of potentially catastrophic climate change impacts [1]. This requires total anthropogenic carbon dioxide (CO_2) emissions to be kept below 2900 billion tonnes by the end of the 21st century [1]. However, current trends indicate that this threshold will be exceeded in the next 15–30 years [1].

Remarkably, although healthcare systems aim at promoting and maintaining the population's health, they have been estimated to be responsible for up to 10 % of greenhouse gas emissions in the United States [2]. In addition, annual greenhouse gas emissions associated with healthcare in the United States have been reported to cause 123,000–381,000 disability-adjusted life-years (DALYs) in future health damages [3]. These numbers underline the need for medical professionals to actively undertake steps to mitigate climate changes related to their profession.

One potentially relevant yet underexposed source of healthcare-associated greenhouse gas emissions is the travel of medical professionals and scientists to conferences [4]. In the field of radiology, the largest annual meeting is the one organized by the Radiological Society of North America (RSNA), which has been held consecutively in Chicago (United States) since 1985. The RSNA annual meeting provides a platform for collaboration, exchange, and dissemination of knowledge. It attracts an audience from around the world that relies on airplane travel to attend this conference. Airplane travel is a well-recognized

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Abbreviations: SSPs, Shared Socio-Economic Pathways; RSNA, Radiological Society of North America; DALYs, disability-adjusted life years; CO_2, carbon dioxide; WHO, World Health Organization; GDP, gross domestic product

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source of greenhouse gas emissions [1]. However, the total amount of greenhouse gas emissions of airplane travel of attendees to the RSNA annual meeting has never been assessed, and its impact on health damage is unclear. This information is important to increase awareness of the magnitude of this issue among the radiological community. It will allow potential attendees to more consciously consider the necessity to physically attend this meeting. It may also trigger congress organizers to further develop and promote climate-friendlier alternatives such as virtual events and interactive live streams, and to consider coverage of CO_2 offset costs (i.e. compensation of emissions by funding an equivalent CO_2 saving elsewhere).

The purpose of this study was therefore to determine the airplane travel-related carbon footprint of the RSNA annual meeting, the associated health burden, and the costs to offset these greenhouse gas emissions.

2. Materials and methods

2.1. Amount of airplane travel-related CO_2 emission

The RSNA's website was used to determine the reported country of origin of attendees to the 2017 meeting that took place in Chicago (United States) from November 26 to December 1 [5]. It was assumed that all attendees had traveled from the airport nearest to the largest city in their country or state to Chicago's O'Hare international airport. For congress attendees from the United States, their state of residence was not reported on the RSNA's website [5]. The number of attendees from different states in the United States was therefore assumed to be directly proportional to the number of radiologists working in each state, according to 2013 data from the Harvey L. Neiman Health Policy Institute [6]. Attendees from the states of Illinois, Wisconsin, Indiana, Michigan, and Kentucky were excluded, because the distance from the largest cities in these states to Chicago is less than 300 miles [7], making road or train travel a more plausible option. The amount of air travel-related CO_2-equivalent emission was calculated using the myclimate flight calculator [8]. This online tool (which uses emission calculations and assumptions in line the European standard DIN EN 16258, wherever possible): 1) calculates flight distance based on the great circle distance (i.e. the shortest distance between two airports) with a detour correction factor; 2) determines fuel consumption per distance based on fuel burn rates from hybrid aircrafts used on short-haul (< 1500 km) and long-haul (> 2500 km) flights, with linear interpolation of the fuel consumption for distances between 1500 and 2500 km; 3) takes into account the CO_2 emission through pre-production of jet fuel/kerosene (including transport and refinery processes) and fuel combustion; 4) allocates some of the total aircraft emissions to the cargo load; 5) distributes the CO_2 emission per aircraft across the average number of passengers on short-haul and long-haul flights for each aircraft type; 6) takes into account a cabin class weighting factor for each aircraft type; and 7) accounts for non-CO_2 aircraft emissions [9]. For the calculation of the total CO_2-equivalent emission, RSNA annual meeting attendees were assumed to have traveled a round-trip in economy class.

2.2. Health burden of airplane travel-related CO_2 emission

CO_2 emission-attributable health damage was assessed using the calculation framework that was recently developed by Tang et al. [10]. The input for this model is derived from the 2014 World Health Organization (WHO) report [11]. DALYs are the sum of the present value of future years of lifetime lost through premature mortality, and the present value of years of future lifetime adjusted for the average severity (frequency and intensity) of any mental or physical disability caused by a disease or injury [12,13]. One DALY can be considered as a loss of one year of healthy life. Importantly, DALYs should not be considered to apply to one single individual, but to the global population. In the model by Tang et al. [10], health damage factors are expressed as DALYs per kg of additional CO_2 emission. The so-called Shared Socio-Economic Pathways (SSPs) are socioeconomic scenarios that examine how global society, demographics, and economics might change over the next century [10]. Health damage factors have been determined for three different socioeconomic scenarios by Tang et al. (10), namely high growth (SSP1), base case (SSP2), and low growth (SSP3) [10]. Health damage factors (DALYs per kg CO_2) for the SSP1, SSP2, and SSP3 scenarios have been reported to be 1.3×10^{-6}, 1.5×10^{-6}, and 2.0×10^{-6}, respectively [10]. The total CO_2-equivalent emission related to airplane travel to the 2017 RSNA annual meeting was multiplied by each of these health damage factors to calculate the DALYs for each of the three projected socioeconomic scenarios. In addition, the contribution of six major health effects (undernutrition, diarrhea, malaria, dengue, heat stress, and coastal floods, as highlighted by the 2014 WHO report [11]) to the total DALYs was displayed, using the same proportions for each health damage factor as reported by Tang et al. [10]. In addition, the contribution of six major health effects (undernutrition, diarrhea, malaria, dengue, heat stress, and coastal floods, as highlighted by the 2014 WHO report [11]) to the total DALYs was displayed, using the same proportions for each health damage factor as used by Tang et al. [10], which were provided to the authors by dr. Tang in a personal communication on February 11th, 2019.

2.3. CO_2 offset costs

CO_2 offsets vary widely in costs, depending on project type, vendor, certifying standard, geographical region, and other factors [14]. The typical costs for rigorously certified offsets from reputable vendors have been reported to be around $9-$15 per ton of CO_2-equivalent emissions [14]. Therefore, an average of $12 per ton of CO_2-equivalent emissions was used to calculate the total CO_2 offsets costs for all airplane travel to the 2017 RSNA annual meeting. CO_2 offsets costs per averted DALY were also calculated. Cost-effectiveness of CO_2 offsetting was determined based on the WHO's threshold (i.e. cost less than three times the per-capita gross domestic product [GDP] per DALY averted) [15], in the United States setting.

3. Results

3.1. Amount of airplane travel-related CO_2 emission

A total of 52,657 attendees were reported to have attended the 2017 RSNA annual meeting [5]. A separate list on the RSNA's website mentioned the number of attendees per country, but this list only included 23,506 attendees (44.6 % of the total number of attendees) [5], on which our analyses were based. The attendees whose country of origin was not reported, probably visited for business reasons or were simply not adequately registered. Of the 23,506 attendees whose country of origin was reported, 12,822 were from the United States, and 10,684 were from 114 other countries [5]. Excluding 1590 attendees from the United States who were more likely to have traveled by road or train to Chicago (520 from Illinois, 215 from Indiana, 144 from Kentucky, 433 from Michigan, and 278 from Wisconsin) 11,232 attendees from the United States remained. The calculated airplane travel-related CO_2-equivalent emissions of these 11,232 attendees from the United States and 10,684 attendees from other countries were 7,067,618 kg and 32,438,420 kg, respectively. This yielded a total airplane travel-related CO_2-equivalent emission of 39,506,038 kg. Tables 1 and 2 show the top 5 states in the United States and top 5 countries outside the United States with regard to number of attendees, CO_2-equivalent emission per economy round-trip, and cumulative CO_2-equivalent emission.

Table 1
Top 5 states in the United States ranked according to total number of attendees to the RSNA annual meeting, CO_2-equivalent emission per single economy round-trip to Chicago, and cumulative CO_2-equivalent emission for all RSNA annual meeting attendees, based on available data for the 2017 RSNA annual meeting [5] and using the online tool myclimate flight calculator [8].

Ranking	Total number of attendees per state to the RSNA annual meeting	CO_2-equivalent emission per single economy round-trip (kg) from each state to Chicago	Cumulative CO_2-equivalent emission (kg) for all RSNA annual meeting attendees per state
1	California (1,426)	Hawaii (2,500)	California (1,568,600)
2	New York (1,066)	Alaska (1,700)	New York (545,792)
3	Texas (879)	Nebraska (1,500)	Texas (534,432)
4	Florida (771)	California, Washington and Oregon (1,100)	Florida (447,180)
5	Pennsylvania (640)		Washington (322,300)
			Total 7,067,618 kg

3.2. Health burden of airplane travel-related CO_2 emission

The total emitted CO_2-equivalent of 39,506,038 kg was calculated to cause 51.4 DALYs ($39,506,038 \times 1.3 \times 10^{-6}$) for SSP1 (high growth), 59.3 DALYs ($39,506,038 \times 1.5 \times 10^{-6}$) for SSP2 (base case), and 79.0 DALYs ($39,506,038 \times 2.0 \times 10^{-6}$) for SSP3 (low growth) socioeconomic scenarios. Fig. 1 displays the contribution of six major health effects to the total DALYs for each socioeconomic scenario. For each of the three socioeconomic scenarios, undernutrition caused the majority of DALYs, followed by malaria, coastal floods/diarrhea, heat stress, and dengue.

3.3. CO_2 offset costs

Offset costs for the emitted CO_2-equivalent of 39,506,038 kg (multiplied by $12 per ton of CO_2-equivalent emissions) were $474,072. CO_2 offsets costs per averted DALY were $9,223 ($474,072/51.4 DALYs) for SSP1 (high growth), $7,994 ($474,072/59.3 DALYs) for SSP2 (base case), and $6,001 ($474,072/79.0 DALYs) for SSP3 (low growth) socioeconomic scenarios.

4. Discussion

With over 50,000 attendees, the RSNA annual meeting ranks third among all medical meetings by total attendance, and is the world's largest radiology conference [16]. This meeting has many potential benefits, in particular the improvement of healthcare by dissemination of new knowledge and technology. However, the present study also reveals a relevant underexposed disadvantage of this meeting, namely the greenhouses gases that are emitted due to airplane travel of attendees. Airplane travel-related greenhouse gas emissions were found to be considerable, with a total CO_2-equivalent emission of 39,506,038 kg. Importantly, this number was calculated based on available data of only 23,506 attendees (representing 44.6 % of the total number of attendees) who attended the 2017 meeting, and is highly likely to be a serious underestimation of the true CO_2-equivalent emission. To put the CO_2-equivalent emission of 39,506,038 kg in perspective, this amount corresponds to the annual CO_2 production of approximately 3689 people living in high-income countries, 10,560 people living in middle-income countries, or 123,072 people living in low-income countries [17]. Furthermore, more than 80 % of these greenhouse gas emissions were attributable to attendees who traveled by airplane from a country

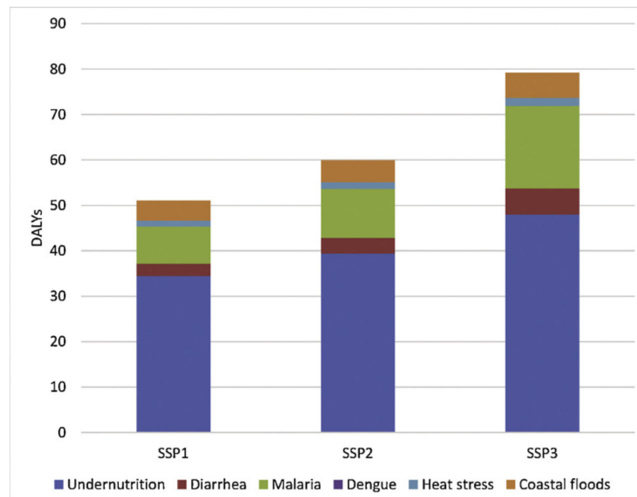

Fig. 1. Contribution of six major health effects (undernutrition, diarrhea, malaria, dengue, heat stress, and coastal floods) to the total DALYs (due to the total emitted CO_2-equivalent of 39,506,038 kg) for each socioeconomic scenario (SSP1 [high growth][1], SSP2 [base case][2], and SSP3 [low growth][3]).
Notes:
[1] In the SSP1 (high growth) socioeconomic scenario, health damage factors for undernutrition, diarrhea, malaria, dengue, heat stress, and coastal floods are 8.73×10^{-7}, 6.77×10^{-8}, 2.08×10^{-7}, 1.16×10^{-10}, 3.23×10^{-8}, and 1.11×10^{-7} DALY per kg CO_2, respectively [10].
[2] In the SSP2 (base case) socioeconomic scenario, health damage factors for undernutrition, diarrhea, malaria, dengue, heat stress, and coastal floods are 9.99×10^{-7}, 8.59×10^{-8}, 2.73×10^{-7}, 1.33×10^{-10}, 3.69×10^{-8}, and 1.22×10^{-7} DALY per kg CO_2, respectively [10].
[3] In the SSP3 (low growth) socioeconomic scenario, health damage factors for undernutrition, diarrhea, malaria, dengue, heat stress, and coastal floods are 1.22×10^{-6}, 1.46×10^{-7}, 4.59×10^{-7}, 1.83×10^{-10}, 4.52×10^{-8}, and 1.39×10^{-7} DALY per kg CO_2, respectively [10].

Table 2
Top 5 countries outside the United States ranked according to total number of attendees to the RSNA annual meeting, CO_2-equivalent emission per single economy round-trip to Chicago, and cumulative CO_2-equivalent emission for all RSNA annual meeting attendees, based on available data for the 2017 RSNA annual meeting [5] and using the online tool myclimate flight calculator [8].

Ranking	Total number of attendees per country to the RSNA annual meeting	CO_2-equivalent emission per single economy round-trip (kg) from each country to Chicago	Cumulative CO_2-equivalent emission (kg) for all RSNA annual meeting attendees per country
1	France (968)	Reunion (6,600)	Japan (2,921,100)
2	Canada (902)	Indonesia (6,500)	China (2,684,000)
3	Brazil (754)	Singapore (6,200)	France (2,420,000)
4	Japan (749)	Australia and Malaysia (6,100)	Brazil (2,412,800)
5	China (610)		Korea (2,056,000)
			Total 32,438,420 kg

outside the Unites States, highlighting the international character of this issue. The health burden of this CO_2-equivalent emission of 39,506,038 kg was calculated to range between 51.4 and 79.0 DALYs, with undernutrition causing most DALYs. Most of this health damage is projected to occur in regions of Southeast Asia, Africa, and the Middle East [10]. These findings on their own can be regarded as troublesome, and are even more disturbing given the fact that the RSNA annual meeting is a medical congress where the majority of its attendees are medical doctors who have been trained to protect, promote and sustain human health.

One potential solution may be to reduce the number of physical attendees by further developing and promoting climate-friendlier alternatives such as virtual events and interactive live streams. This may potentially even increase the meeting's reach. However, it has also been reported that the majority of attendees (76 %) come to see new products, and the majority of attendees (80 %) have a role in purchasing [5]. Another potential and perhaps more practical option that may be realized immediately, is offsetting the carbon footprint of airplane travel. CO_2 offsetting refers to compensation of emissions by funding an equivalent CO_2 saving elsewhere, such as by investing in renewable energy projects, energy-efficiency improvements, and tree-planting activities. Importantly, the incremental cost-effectiveness ratio of offsetting airplane travel-related greenhouse gas emissions was calculated to vary between $6,001 and $9,223 per DALY averted, depending on the socioeconomic scenario. This is far below three times the GDP per capita in the United States [18], and can thus be regarded as highly cost-effective according to the WHO's threshold for cost-effectiveness [15].

The debate is open as to who should be held responsible for these CO_2 offsets costs. Three parties that should be considered are the attendees who rely on airplane travel to attend the RSNA annual meeting, the RSNA, and the city of Chicago. Interestingly, a survey study has shown that 75 % of airplane travelers are willing to pay a carbon travel tax in addition to the price of their airplane ticket [19]. This study also found differences between continents, with slightly more Europeans (80 %) than North Americans (75 %) willing to pay in principle, and Asian travelers (59 %) being least willing to pay for a carbon travel tax [19]. The latter finding is important, given the fact that three Asian countries (Japan, China, and Korea) were in the top 5 of counties outside the United States with regard to cumulative airplane travel-related CO_2 equivalent emission (Table 2). Therefore, it cannot be assumed that attendees to the RSNA annual meeting will take the initiative to cover these costs by themselves. Incorporation of CO_2 offset costs in registration fees may be an option. However, meeting organizers, together with the city of Chicago, may also consider allocating other funds for this purpose, particularly in light of the fact that attendees have been reported to contribute $160 million to Chicago's economy per annual meeting [20].

There is a scant literature on the airplane travel-related carbon footprint of medical meetings and its consequences. The European Respiratory Society 's annual congress that took place in Munich in 2006, which had a total attendance 17,240, was estimated to cause a carbon footprint for all travel of 3,920,000 kg of CO_2 [21]. The American Thoracic Society International Conference that was held in San Diego in 2006, hosted approximately 15,000 visitors, and the airplane travel to and from this meeting was reported to cause a total CO_2 emission of 10,779,000 kg [22]. Airplane travel of approximately 30,000 attendees to the 2014 annual meeting of the Society for Neuroscience in Washington DC was estimated to account for a total CO_2 emission of 22,000,000 kg [23]. These three meetings comprised only 9.9 %, 27.3 %, and 55.7 % of the estimated airplane travel-related carbon footprint of the 2017 RSNA annual meeting, respectively. Moreover, these previous studies did not address the associated health burden and the cost-effectiveness of carbon offsetting.

The present study had some limitations. First, this study used available data of only 23,506 people (44.6 %) who attended the 2017 RSNA annual meeting, and it did not take into account greenhouse gas emissions due to other causes than airplane travel. Second, it was assumed that RSNA annual meeting attendees had traveled in economy class, but a considerable proportion may have traveled in business class that corresponds to a higher per-person CO_2-equivalent emission. Therefore, the calculated carbon footprint of the RSNA annual meeting and its health effects have likely been considerably underestimated. Third, estimates of health impacts that were calculated with the framework that was developed by Tang et al. [10] are prone to some degree of uncertainty due to quantitative assumptions used.

In conclusion, the airplane travel-related carbon footprint of the RSNA annual meeting and the associated disease burden are relevant, and potential attendees and organizers should take measures to overcome this undesired side effect. Offsetting this carbon footprint is cost-effective and this initiative should be taken by the radiological community.

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Declaration of Competing Interest

Both authors declare that they have no conflicts of interest.

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