Impact of scientific conferences on climate change and how to make them eco-friendly and inclusive: A scoping review

Carl Froilan D. Leochico MD , Melina Longoni Di Giusto MD , Ramiro Mitre MSc

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Author names and affiliations:
Carl Froilan D. Leochico, MD[a,b,*], Melina Longoni Di Giusto, MD[c,d,e,f], Ramiro Mitre, MSc[e,f]

[a]Department of Physical Medicine and Rehabilitation, St. Luke's Medical Center, Global City and Quezon City, Philippines

[b]Department of Rehabilitation Medicine, College of Medicine and Philippine General Hospital, University of the Philippines Manila, Manila, Philippines

[c]Department of Disability of the Municipality of Ituzaingó, Buenos Aires, Argentina

[d]ReDel Rehabilitation Center, Buenos Aires, Argentina

[e]Universidad Abierta Interamericana, Rosario, Santa Fe, Argentina

[f]Fundación Neurodiversidad, Rosario, Santa Fe, Argentina

[*]*Corresponding author:*
CARL FROILAN D. LEOCHICO, MD
Department of Physical Medicine and Rehabilitation, St. Luke's Medical Center - Global City, Rizal Drive cor. 32nd St. and 5th Ave., Taguig, 1634 Metro Manila, Philippines
E-mail address: cfdleochico@stlukes.com.ph
Contact number: (+63) 917 110 2275
ORCID iD: 0000-0003-2928-2083

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Abstract

Scientific conferences are integral to all fields of study, providing learners of all ages with opportunities to improve their practices, resulting in advancements that may benefit the greater population. Traditionally, conferences are conducted in-person, entailing attendees to travel and consequently generate carbon dioxide. Aside from air travel that largely contributes to carbon emissions, conference-related equipment and accoutrements and various activities related to travel can negatively impact the environment. Especially during the COVID-19 pandemic, the value of digitizing conferences through synchronous and/or asynchronous Internet-dependent techniques has been greatly recognized. Among the benefits of online or hybrid conferences, significant reductions in carbon footprint and various forms of waste (time, funds, resources, energy) are summarized in this scoping review. Based on the conference-related experiences from 11 included studies, this review also presents practical ways to organize eco-friendly and inclusive conferences, whether conducted in-person, online, or via a combination of both.

Keywords: Conference, carbon footprint, climate change, sustainability, scoping review.

1. Introduction

The health of a population, to stay in a sustainable state, requires clean air and drinking water, adequate food, tolerable temperature, stable climate, protection against ultraviolet (UV) solar radiation and high levels of biodiversity [1,2]. Climate change affects health through a multitude

of mechanisms, including heat, poor air quality, and extreme weather events, as well as weather changes that alter vector-borne diseases, reduce water quality, and decrease food security [3]. The health risks associated with these routes of exposure are mediated by physiological, cultural, and socioeconomic vulnerabilities [4]. Disability is one of the factors that increases vulnerability and exposure to climate change [5]. With disability disproportionately affecting already vulnerable populations (e.g., people from developing economies, elderly, with low educational attainment, low-income earners, unemployed, children from poor households, members of ethnic minority groups) [6], people with disabilities are put at an even greater risk of the direct and indirect effects of climate change.

By 2050, climate change will mainly aggravate existing health problems, and populations that are currently most affected by climate-related diseases will also be at greater risk in the future [7]. Since the health impacts of climate change will not be the same for all due to the differential exposure, sensitivity, and adaptability of individuals and groups [8], not only should the scientific community educate the public on the effects of climate change, but also serve as role models in putting knowledge into practice. In particular, the public needs practical examples on how to contribute to the reduction of carbon emissions through their work-related activities such as large gatherings or meetings, which are equivalent to scientific conferences among professionals in the healthcare sector. However, large scientific conferences aimed at enhancing health-related knowledge, ironically, often implies leaving huge carbon footprints, a practice that may seem contrary to what healthcare professionals are advocating.

Conferences, congresses, workshops, and other kinds of scientific meetings are a very important aspect of research and development, and they constitute a way for professionals to exchange their relevant findings and experiences in one place. Across all professions, scientific meetings

are necessary to constantly update the growing body of knowledge ultimately for the purpose of uplifting the standard of living of humanity [9]. In healthcare, advancements in the way diseases are evaluated and managed are largely influenced by scientific research, collaborations, and educational opportunities. Some of the reasons that make scientific meetings or educational sessions among healthcare professionals fundamental include professional development, updating of current health standards and protocols, improving disease diagnosis and treatment, and ensuring patient safety and quality of care by replacing outdated knowledge, processes and technologies.

However, there are some downsides to the traditional in-person way of conducting scientific meetings. A substantial carbon footprint for each attendee can potentially be generated, in addition to being time-consuming and costly to travel [10]. Air travel is among the biggest sources of conference-related emissions in the form of aircraft burn fuel releasing greenhouse gases (GHG), particles and condensation trails (contrails), which negatively contribute to climate change [7]. About 4-5% of global emissions each year comes from air travel [11,12]. Other factors like delegate travel, accommodation and food requirements, as well as the use of audiovisual equipment, and printing or manufacturing of single-use items like conference booklets, lanyards, posters, and beverage containers also carry an ecological footprint [12]. Considering these potential sources of carbon emissions from sometimes thousands of professionals needing to travel from all over the world, education without borders through online conferences may seem like a practical solution. Studies have shown that online education can achieve a large reduction in carbon emissions and, therefore, could help in energy efficiency and sustainability [13]. Furthermore, moving scientific conferences online may help resolve several barriers to in-person conferences, such as geographical distance, costs, physical inaccessibility,

safety issues, time constraints, and difficulties in traveling particularly among persons with disability and those with caring, parental, or work responsibilities [14,15]. Either replacing or supplementing in-person conferences with virtual ones would help address both issues of accessibility and carbon footprint by reducing travel costs and distances among other barriers. Virtual conferencing is used as a cost-effective way of providing educational resources remotely to a wider population [16].

The coming of coronavirus disease 2019 (COVID-19) raised a scenario of urgent need to exchange timely and relevant knowledge among experts and members of the scientific community across disciplines through online conferences. Before the pandemic, online education has traditionally been viewed as an alternative, if not inferior or impersonal, way of learning [17]. Nonetheless, to observe physical distancing during the pandemic many educators and students of all ages and backgrounds have learned to adapt relatively quickly to virtual learning [18].

However, despite several promising examples of either purely virtual or hybrid (in-person plus virtual) conferences, the uptake of virtual conferencing has been lower than it ought to be amid its known potential benefits [19]. The following are some of the barriers to virtual conferencing: access to or unreliability of technology, effectiveness and safety of communicating and networking online, notion that virtual formats will never be as good as face-to-face interaction [19], distraction/ multitasking of attendees or learners, and impaired social interactions. Such barriers can possibly make it difficult to teach and learn practical and clinical information [20].

Acknowledging that online scientific conferences can never completely replace in-person ones, their theoretical benefits to the environment highlighted in prior studies need to be leveraged to promote sustainable academia, referring to “individual, collective, and institutional

practices…responsive to current and future generation needs…" [21,22]. Currently, there exists a general lack of awareness or recognition among the academic or professional community of the different advantages of purely online or hybrid scientific conferences, especially as they relate to climate change and inclusivity [23]. According to Parncutt et al., many universities continue to provide reimbursements for academic travel expenses, encouraging air travel [23]. Raising awareness by providing concrete evidence-based ways on how to create eco-friendly and inclusive conferences may help slow down climate change and move many professional individuals and groups into action. Therefore, this scoping review aimed to summarize the advantages of online or hybrid academic conferences over in-person conferences with emphasis on their impact on climate change. The study also synthesized examples from the literature of how to organize environment-friendly and inclusive conferences.

2. Methods

Following the methodological framework of Arksey and O'Malley [24], this scoping review was conducted to map the key concepts underpinning the topic of interest using available literature without restrictions to study designs and publication date preceding the search. The review process, albeit iterative and flexible rather than strict and linear, was structured according to the following stages:

2.1. Identification of the research question

We stated our research question as, *"What is known from the literature about online or hybrid academic conferences in comparison to in-person conferences with respect to climate change?"*

2.2. Identification of relevant studies

On July 5, 2021, we searched the MEDLINE/ PubMed and EBSCO electronic healthcare databases, which we have free access to, in identifying relevant studies. The Medical Subject Headings (MeSH) and free search terms were used as follows: *(Climate change) AND ((Videoconference) OR (virtual meeting) OR (online conference) OR (virtual conference) OR (online meeting) OR (academic travel) OR (digital meeting) OR (digital conference) OR (webinar) OR (virtual congress) OR (online congress) OR (digital congress))*.

2.3. Selection of studies

We included peer-reviewed papers that presented either actual or hypothetical experiences with in-person, purely online, or hybrid scientific conferences and their impact on climate change. Our initial search resulted in a large number of mishits, including duplicates, study protocols, books, and other publications not deemed relevant and were therefore excluded. We also excluded from our analysis papers that focused on telemedicine as a service delivery technique rather than as a way to gather and educate a large number of people online and those that did not discuss climate change. In addition, papers that were not available in English or Spanish and those that did not have freely available full text were excluded. For an organized presentation of our study flow, Figure 1 lists the number of studies included and excluded per step according to the diagram adapted from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement [25].

2.4. Charting of data

Based on our consensus as to what information should be collected from the included studies to help us answer our research question, the following key items were obtained: lead author of the article; journal and year the article was published in; article type and objective; name of the actual or hypothetical conference and method of conducting it (either in-person, online, or

hybrid); actual or projected number and demographics of attendees, as well as registration fee, if mentioned; effects of conferences on climate change; and other benefits of scientific conferences if done online (Table 1). After drawing the lessons that can be gained from the practical examples or points raised from each included article, we came up with a list of suggestions or tips in organizing eco-friendly and inclusive conferences (Table 2).

2.5. Reporting of results

Lastly, we summarized and analyzed pertinent data from the included studies in a narrative, presenting them in tallies, groups, or themes, wherever applicable. It was beyond the scope of our review to critique the methods and outcomes of each included study. Being a scoping review, the quality assessment of individual articles was not necessary [24], as long as each publication came from a reputable, peer-reviewed journal. In addition, this study did not attempt to synthesize evidence or aggregate available data.

In this study, we did not include the final step (stakeholder consultation), considered as "optional extra" according to Arksey and O'Malley [24], considering that the charted data already seemed sufficient to answer our research question.

3. Results

A total of 146 articles were identified from the electronic search. Of these, 110 did not proceed beyond the screening stage for reasons cited in Figure 1. Of the remaining 36 articles, 25 more were excluded due to any of the following: unavailable full text; did not include conference-

related data on climate change; focused on telemedicine as service delivery; or not a scientific conference for continuing professional development.

The 11 papers that reached analysis were published in a diverse range of peer-reviewed journals. Among the included studies, the oldest was published in 2010 [26], while the most recent was published online in March 2021 [21]. The majority of studies were published in 2020. Four papers were considered narratives [27–30], while three papers were original articles that compared carbon emissions produced from in-person versus online conferences [12,21,26].

The studies used different terms to refer to the three general modes of conducting scientific conferences: in-person (also known as traditional, legacy, physical); online (virtual, digital, remote, webinar); and hybrid (mix of in-person and virtual). As reported by Abbott, the hybrid mode could be exemplified by a hub-and-spoke model, such as one of the conferences of the European Biological Rhythms Society that had set up major/large hubs (allowing two-way interaction between the hub and each spoke) and minor/small hubs (allowing one-way transmission from the hub to the spokes) [31]. As shown in Table 1, three studies from the following lead authors and publication year analyzed the climate change impact of actual or real-life, rather than hypothetical, online conferences: Achakulvisut in 2020 (Neuromatch, an online neuroscience conference) [10], Counsell in 2020 (low-carbon emission conference for the Global Coral Reef Week) [32], and El Amiri in 2020 (webinar series on climate change organized by the Working Group on Climate Change and Health) [28]. One study (Milford 2020) discussed the potential climate change effects of seven in-person pediatric urology conferences that had transpired from 2013 to 2019, and compared them with the projected benefits had online conferences been conducted instead [12]. On the other hand, two studies (Anderson 2010; Duane 2021) discussed the potential climate change effects of an online conference that had actually

transpired (Pediatric Cardiology webinar; Supporting Deaf People conference), and compared them with the projected consequences had an in-person conference been conducted instead [21,26]. Meanwhile, four studies presented their experiences with actual in-person conferences and their potential effects on climate change without making comparison to a hypothetical or actual online conference [27,29,30,33].

Among the online conferences that actually happened either synchronously (live/real-time) or asynchronously (prerecorded), one or more of the following platforms was/were used: conference website, Crowdcast, Wimba, YouTube, Zoom, and/or an institutional online educational platform. Social media marketing and presence were also utilized, such as Facebook, Instagram, and/or Twitter. Regarding inclusivity, one study reported use of videos with sign language uploaded on the conference website [26].

Regardless of the mode of conference used, all studies showed huge conference attendance nearing at least 1,000 from all over the world, except for the website-based webinar series on climate change reported by El Amiri with possibly local attendees of approximately 40-60 per episode [28]. The largest number of attendees (28,000) was reported from the 2019 fall meeting of the American Geophysical Union held in San Francisco, California [33]. Three studies reported free registration for all to online conferences [10,21,32]. One study estimated that the cost per participant differed substantially between a hypothetical in-person conference (more than $2,500 for airfare plus $350 for registration fees) versus an actual online conference ($69 for registration fees) [26].

Eight out of 11 studies estimated carbon emissions of in-person scientific conferences (Table 1). All these estimates solely considered emissions from air travel in the computation. Most of the numerical data (usually in metric tons) were reported as total emissions per conference, rather

than per attendee. The formulae used to compute the emissions varied among the studies, but they generally considered the number of conferences, venue of the in-person conference/s, cities where attendees came from, number of attendees, one-way flights versus return trips, and presence of hubs. One study used the X-ray Integral Field Unit (X-IFU) calculator to quantify carbon footprint, and it was the same study that reported the largest carbon emissions (50,500 tons) from a huge in-person conference attended by >24,000 scientists worldwide [30]. No study quantified emissions coming from sources besides air travel, such as other modes of transportation, and utilization of conference-related and side trip-related hospitality, food service (e.g., single-use plates, utensils, beverage containers), and various equipment (e.g., audiovisual materials, gadgets) and accoutrements (e.g., conference or tourist booklets, brochures, tote bags, souvenirs) [12]. Nonetheless, these other sources of carbon emissions were briefly mentioned in a few studies [12,26,27,30].

In a life-cycle assessment comparing between an actual online and a hypothetical in-person pediatric cardiology conference, the former performed better across all 16 environmental sustainability impact categories (e.g., climate change, acidification, freshwater ecotoxicity, ionizing radiation, ozone depletion, fossil fuel use, land use, mineral/ metal use, water use, etc.) [21]. The authors found that an online conference could provide 98% reduction in climate change impact (4 versus 192 tons from online versus in-person conference, respectively) [21].

Aside from their positive ecological impact, online scientific conferences afford a multitude of benefits (Table 1), such as huge savings in time, costs (foreseen and unforeseen), travel, energy, and health (e.g., less risk of COVID-19 infection, jet lag, insomnia, noise, social strain, work-related stressors) [12,30–32]. In addition, they foster diversity and inclusivity, overcoming geographical, cultural, resource, and disability-related barriers [10,12,28].

Synthesized from the included studies, practical tips when organizing either an in-person, online, or hybrid conference and making it as eco-friendly and inclusive as possible are presented in Table 2. These tips are geared towards promoting environmentally sustainable practices, reducing waste and ecological footprint, and innovating equitable solutions, while providing a worthwhile and rich learning experience regardless of the conference mode. For instance, the total carbon footprint of the conference and per participant can be kept as low as possible by strategically organizing the annual number and venue of in-person conferences, encouraging surface and public transport, and avoiding use of non-recyclable accoutrements [12,30,33]. Lastly, online conferences can foster active participation from academics across the world, overcoming financial, mobility and time constraints, by having reduced or free registration fees and archived, open-access virtual content with minimum Internet requirements [31,33].

4. Discussion

Regardless of the field of study, scientific or academic conferences (also known as continuing professional development in the health sciences) are fundamental in providing opportunities to learners of all ages to meet and exchange relevant updates and ideas that lead to improvement and progress. They foster "continuous acquisition of new knowledge, skills, and attitudes to enable competent practice" [34]. Before the COVID-19 crisis, conferences were largely conducted in-person, while the minority of them were either purely online or a combination of in-person and online modes (hybrid). While there are undeniably many benefits from conducting in-person conferences (e.g., greater opportunities for social interaction, intellectual debates, research collaborations, jobs, career development, and travel), they also have negative consequences, particularly to the environment (climate change) and the disadvantaged (persons affected by geographical, physical, psychological, sociocultural, and financial barriers to

attending in-person conferences). Based on the data gathered in this scoping review, in-person conferences generate massive carbon footprints, waste of resources, time and energy, and unequal access and opportunities, which are all addressed by online conferences [10].

To protect people from COVID-19 and adhere to government-imposed quarantine measures, national, international, or large in-person scientific conferences were rescheduled indefinitely or converted to online conferences. In areas with limited financial resources, this digital shift greatly benefited students, graduates, and professionals, who could not afford the costs of the registration fee and travel to an in-person conference. However, the shift was not without challenges especially in countries and rural settings with inadequate digital infrastructure to support reliable Internet connection. These challenges may be attributed to the lack of fiberoptic lines, cell towers, routers and/or stable electricity [35,36]. Nonetheless, the value of online educational opportunities has been recognized as a useful and inclusive tool by numerous government and non-government organizations or institutions catering to vulnerable populations (e.g., children, elderly, persons with disability) and their care providers. A call to action is necessary to mitigate the so-called “digital divide,” such as by lobbying for policies that can provide and sustain access to applications without data costs, reduce Internet connectivity taxes, and implement feasible and cost-effective wireless technologies [35,36].

As responsible professionals with an obligation to do no harm, it is prudent to practice what we preach and serve as role models in protecting and sustaining our environment. The carbon emissions from unnecessary travels can be minimized in a lot of ways, such as those found in the literature and collated in this study. Professional societies need to begin reshaping the way conferences are organized. For instance, conducting national or international in-person conferences once a year and digitizing the quarterly or midyear meetings can significantly reduce

carbon emissions. Following the hub-and-spoke model, conferences can also be rotated among different geographical regions. In-person conferences need to be carefully scheduled, preferably avoiding fall and winter when leaves decay, emitting carbon dioxide [37], or rainy days when people need to burn fuel and travel on wheels to keep warm. Careful planning also includes choosing a strategic venue accessible by foot or less carbon-emitting modes of transportation for the majority of the participants, favoring use of recyclable over single-use conference items, serving plant-based meals, and offering participants and exhibitors options to offset their conference-related carbon emissions. In addition, since air travel is a huge carbon dioxide generator, additional international tax on airfares especially for those attending in-person mega conferences may be considered to encourage the public to prefer online modes, whenever available.

The results of this study should be interpreted in the light of the following limitations: (1) only articles in English and Spanish were included, possibly missing important articles available in other languages; (2) the studies came from only two, albeit large and reputable, search engines to which we had either free or institutional access; and (3) the quality of evidence of the included studies was not assessed, a limitation inherent to scoping reviews [24]; hence, findings might not be generalizable. Even though the search could have been more exhaustive, the practical examples tabulated in this review based on the 11 included studies can provide a quick and easy reference of the advantages of online over in-person conferences, and how to make them eco-friendly and inclusive. Further research may aim to analyze the actual or hypothetical contributions of individual or combined techniques in reducing carbon emissions from conferences as guide in formulating appropriate and evidence-based recommendations.

5. Conclusion

As local and national governments struggle to fight the pandemic, it is never too late to start preparing for yet another global crisis of our time, the environmental and health-related consequences of climate change. Moving forward, there is a need to bring various stakeholders (professionals across all fields, healthcare providers and consumers, policymakers, relevant industries) into climate change awareness and action so that individual and collective efforts are carried out through "green and sustainable conferences."

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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7. Author contributions

CFDL: conceptualization; data curation; analysis; writing - original draft; writing - review & editing. MLDG: conceptualization; data curation; writing - original draft; writing - review & editing. RM: conceptualization; data curation; writing - original draft; writing - review & editing.

8. Financial disclosure/ conflict of interest

The authors had no conflict of interest to disclose.

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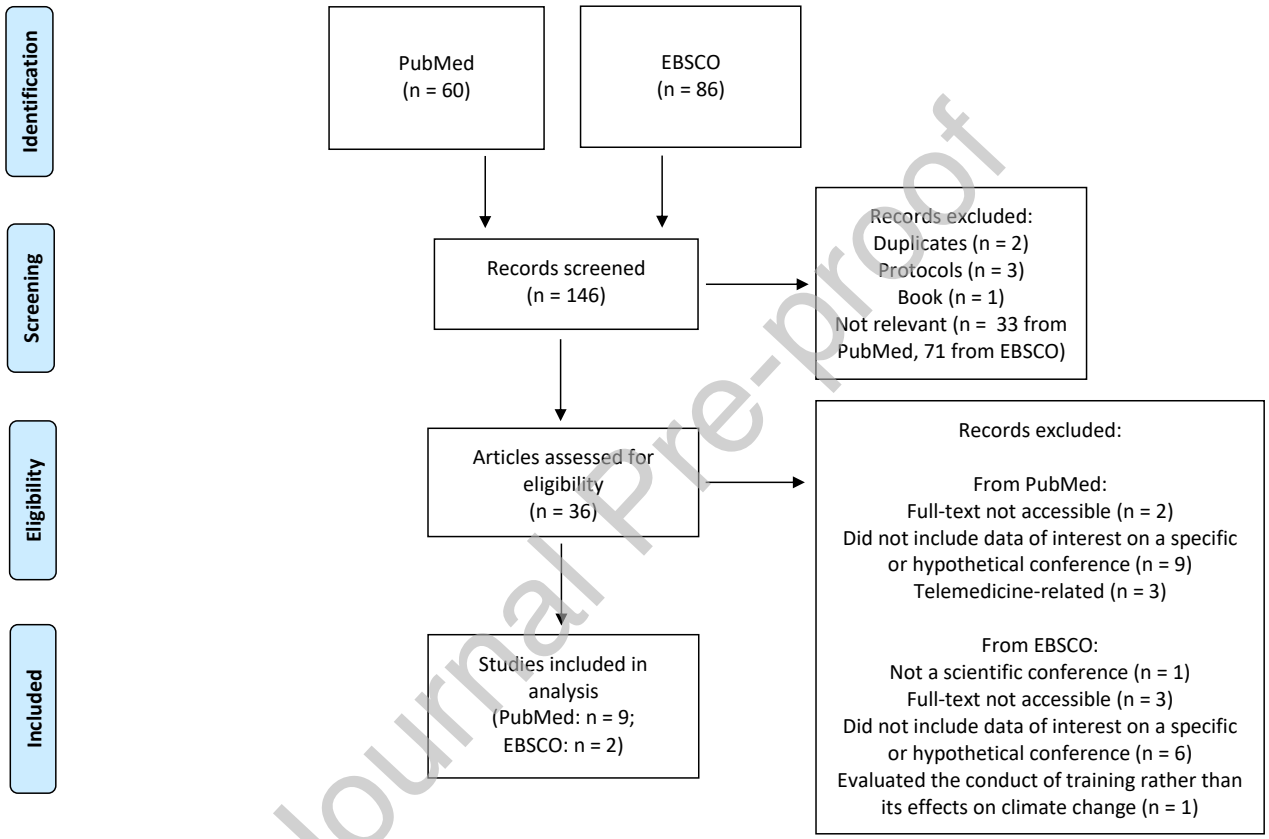

Figure 1: Study flow diagram.

From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement [25].

Table 1. Impact of scientific conferences on climate change and their benefits if done online based on included studies (N = 11).

Lead author, journal, publication year | Article type [Reference]	Objective of the paper | Name and conduct of the in-person and/or online conference (if applicable)	Number & demographics of attendees | Registration fee, if available	Effects of the scientific conference on climate change	Benefits of an online conference
Counsell, Biology Open, 2020 | Meeting review [32]	To document approach to organizing and hosting a low-carbon emission conference for the Global Coral Reef Week (GCRW) | Recorded presentations and workshops uploaded to a dedicated YouTube channel; live-streamed plenary talks and workshops available in Zoom, YouTube, and conference website; networking sessions via rotations through breakout rooms; social media marketing (Instagram, Twitter, Facebook)	2,700 attendees worldwide | Registration: <$10 per presenter and <$0.50 per attendee, which were covered by a grant, sponsors, and donations	Decreases CO_2 emissions: average amount of carbon emission from travel to a research conference calculated at ~800 kg per presenter,[38] while a one-way intercontinental flight estimated to release more CO_2 (3000 kg) than the average annual emissions for one person living in Britain or ten people living in Ghana [33]	Eliminates scheduling conflicts Enables rewinding, pausing, and re-watching Facilitates broad content sharing with current or future colleagues, employers, advisors, students, resource managers, politicians, media, and community partners Provides anyone with Internet access an opportunity to learn about current coral reef science beyond the end of the conference Increases accessibility for participants experiencing personal life events or disabilities (e.g., deaf or with limited understanding of the language through auto-translation subtitles) Offers a variety of health benefits for attendees (e.g., reduced exposure to germs, misalignment of the circadian rhythm, radiation, engine noise, social strain from leaving families, and stress from interrupted work) Offers learning to diverse socioeconomic backgrounds, including those unable to afford registration and travel costs of in-person conferences
Achakulvisut, eLife, 2020 | Feature [10]	To document the experiences in setting up Neuromatch, an online neuroscience conference | Live or recorded poster presentations in parallel sessions via Zoom or Crowdcast; single track for invited and contributed talks delivered live and recordings made available immediately after each session; 15-minute chats or one-on-one meetings between attendees and algorithmically matched like-minded scientists	3,000 registered viewers worldwide on Crowdcast; majority were graduate students (47,3%), postdocs (19.9%), and professors (11.7%); 468 signed up for the one-on-one matched meetings; 912 engaged in the live session concurrently; >100 simultaneously watched on YouTube | Free registration	Shifting from legacy (traditional) to online conferences can "make science better and be less harmful to the environment"	No space and temporal limitations Extremely quick and less burdensome to organize with a small team No location needed; no venues, accommodations, or travels to book; no projectors, caterers, or entertainment Worldwide pool of remote volunteers Speakers more available due to time flexibility Diversity and inclusivity of participants, overcoming family duties, gender bias, disabilities, travel bans, visa requirements, limited funding, religious practices, etc.

El Amiri, Can J Public Health, 2020 | Narrative [28]	To reflect on the activities of the Working Group on Climate Change and Health (WGCCH) to date and critically examine them in the context of its evolution towards a Community of Practice (CoP) | Webinar series on climate change (e.g., food security, urban water shortages, maternal health, wildfires, invasive species, infectious disease, population health within and outside Canada) from both research and practitioner perspectives; recorded and published online along with additional information resources as a living compendium of knowledge	40-60 attendees per live webinar; significantly higher reach based on website activity	Remote participation for presenters and attendees removes unnecessary travel and geographical barriers; promotes collaborative and mutual learning to address complex issues of climate change and innovate more equitable solutions; sensitizing, engaging, and networking diverse audiences to climate change and associated health issues encourage lifelong learning and awareness; audiences better equipped to inform and provide health education and policy guidance	Capacity building Knowledge sharing Research collaboration Global partnering Shared benefits and responsiveness to causes of inequity Professional development across diverse disciplines and regions Resources generation Development of training materials Inclusivity and diversity Heightened empowerment to act through the CoP and webinars Exchange of best practices
Abbott, Nature, 2019 | News [31]	To evaluate whether technology and organizational techniques can help interaction and networking by enabling seamless discussion across different locations, and encouraging participants at all sites to hold social events, such as a 5-hour pop-up conference of the European Biological Rhythms Society (EBRS) | Hybrid conference: virtual and in-person; talks broadcast from Munich to 5 major two-way hubs and 69 small one-way hubs across 18 time zones worldwide; social media presence accommodated questions or comments posted on Twitter	At least 450 people attended the conference and nearly 60% joined in through Twitter interactive hubs; ~10% more people attended the virtual meeting than the in-person conference in Lyon, France| Free registration for students	Reduces carbon footprints from globetrotting activities	Offers a huge opportunity to think innovatively about how scientific discussions take place No travel time and energy lost Students can attend for free Freedom from bureaucracy involved in booking flights Parents with difficulty in arranging travel can attend Opportunity to offset emissions by buying carbon credits is not the way for the future as it does not change travel behavior

Milford, J Pediatr Surg, 2020 | Non-clinical, retrospective comparative study [12]	To estimate the carbon footprint of poster and podium presenters traveling to the Societies for Pediatric Urology (SPU) fall conferences between 2013 and 2019, as well as the 2015 European Society of Pediatric Urology (ESPU) conference | In-person versus hypothetical online conference	Total of 983 presenters; majority from the USA (79%) for the 6 fall SPU meetings and from Europe (43%) for the 2015 ESPU	Estimated carbon emissions from total round-trip miles traveled for all 7 conferences: 912.47 metric tons (equivalent to melting of ~2,737.41 m^2 of Arctic summer ice); shorter round trips for meetings held in Southeastern Canada (Montreal) and Southern USA (Atlanta, Dallas, Miami Beach) compared to Western USA (Scottsdale, Nevada) and Europe (Prague) Online conferences can decrease carbon emissions from ground and air transport to and from conference venues, utilization of the hospitality and food service industry, manufacture and transport of conference posters, and utilization of audiovisual equipment	Broader healthcare community worldwide can engage in environmentally sustainable practices More modest emissions from video streaming, which is likely to be more efficient with technology improvements [39] More accessible to those in remote locations, with time and resource constraints [19], or with travel issues due to local or international restrictions Sessions recorded and saved for posterity More sustainable options than single-use conference items (e.g., booklets, lanyards, plastic water bottles and coffee cups Carbon offsetting as an option to delegates, contributing to projects that balance carbon footprints like investment in renewable energy projects or tree planting [40]
Klöwer, Nature, 2020 | Comment [33]	To analyze potential emissions savings from reducing conference travel, conducting a biennial conference in accessible locations, having regional hubs, and increasing virtual presentations | American Geophysical Union (AGU) 2019 fall meeting in San Francisco, California, USA	28,000 attendees, including presenters, from North America, East Asia, and Europe; ~92% traveled >400 km by plane to attend a conference in-person	75% of the total emissions came from flights longer than 8,000 km (36% of attendees or 10,000 people); emissions from one-way flights of 2,266 people from China generated 13,600 tons of CO_2; a return trip for 1 person from London (17,200 km) generated 4.4 tons of CO_2	Time differences can be accommodated Equality and equity Early-career researchers can gain exposure to the global community People with personal difficulties (e.g., lack of childcare, budget, or visa) can attend virtually Inclusivity
Bousema, Am J Trop Med Hyg, 2020 | Narrative [29]	To calculate air travel distances and their associated carbon emissions from the 2019 annual conference of the American Society of Tropical Medicine and Hygiene (ASTMH) in Maryland, USA	4,834 attendees came from 110 countries across 6 continents	Participants traveled a total of 27.7 million miles flown, generating ~8,646 metric tons of CO_2 emissions	Can facilitate frequent scientific interactions without the need for travel Improves conference accessibility Gains in travel costs and time

Barret, Experimental Astronomy, 2020 | Narrative [30]	To discuss the main features of the X-ray Integral Field Unit (X-IFU) carbon footprint calculator and describe two illustrative applications: (1) 2019 fall annual meeting of the American Geoscience Union (AGU); and (2) 4 Lead Author Meetings (LAM) of the 6th assessment report of the Intergovernmental Panel on Climate Change (IPCC) working group I	AGU: >24,000 scientists from >100 countries IPCC LAM: Guangzhou, China (215 participants); Vancouver, Canada (222); Toulouse, France (248); and Santiago, Chile (304)	AGU: in-person conference in San Francisco generated ~50,500 tons of CO_2 emissions (based on X-IFU) that could have been reduced by: (1) 76% had the 36% highest emitting attendees (from almost every country outside North America) participated virtually, and (2) 70% had there been 3 hubs (Chicago, Seoul, Paris) even with all in-person participants IPCC LAM: all 4 meetings generated ~2,700 tons of CO_2 emissions spread over 4 weeks (equivalent to the annual footprint of ~400 people)	Waste reduction can also be done using reusable items Increases attendance and efficiency due to time saved from traveling Each contributing country can receive equal and proper representation in virtual meetings Lessens risks of jet lags, fatigue, and lost time and productivity
Duane, Cardiology in the Young, 2021 | Life cycle assessment [21]	To analyze the differences between the environmental footprint of a pediatric cardiology webinar with a hypothetical in-person conference (typically lasting 2.5 days per biannual conference) | Webinar entitled, "Tetralogy of Fallot: How can we avoid poor outcomes late after repair?", organized by the Heart University (an online educational platform hosted by the Cincinnati Children's Hospital)	1,374 healthcare providers for both congenital and pediatric acquired heart disease from 100 countries across 6 different continents | Free registration	Online conference performed better than hypothetical in-person conference across all 16 environmental sustainability impact categories (e.g., climate change, acidification, freshwater ecotoxicity, ionizing radiation, ozone depletion, fossil fuel use, land use, mineral/ metal use, water use, etc.) Online conference generated 4 tons of CO_2 equivalent compared to 192 tons for in-person conference Resource use for in-person conference equivalent to 400 times what an average person would use in 1 year; climate change and photochemical ozone formation ~250 times Online conference reduced the climate change impact by 98%	Webinars may be a practical and sustainable way of providing high quality medical education and sharing knowledge Interactions and linkages can be enriched by attendees from diverse countries and financial backgrounds Enhances opportunity for attendees to message/chat/inquire/discuss in real time May have no time limits for open forum associated with in-person conferences Caters to attendees from lower resource settings with limited specialists, heavy workload, and no funding for academic travel Provides networking opportunities

Anderson, Canadian Journal of Learning and Technology, 2010 | Original article [26]	To examine the potential environmental effects of travel to a hypothetical in-person versus actual online | Supporting Deaf People Conference (SDP) in 2008 conducted entirely online for 4 days through pre-recorded materials in print, PowerPoint presentations, and videos with sign language uploaded on the conference website; live sessions used a videoconferencing platform, Wimba	241 presenters and participants from 18 countries mostly across the United Kingdom, Europe, Africa, and Middle East | Registration fees alone: in-person ($350) versus online ($69)	Average CO_2 emissions per participant had the in-person conference been held in London: 1.79 tons	Significantly reduces participants' conference-related foreseen and unforeseen financial costs (average total cost per participant flying to London: $2,505.05 versus $69 for online participants) Minimizes lost productivity (work hours) and opportunities (while away from work) while traveling Savings from carbon offset purchases (~$36) for those concerned with the environmental impact of in-person conference
Desiere, EuroChoices, 2015 | Narrative [27]	To calculate the carbon emissions from air travel during the 2014 Congress of the European Association of Agricultural Economists (EAAE) in Ljubljana, Slovenia, and propose strategies to reduce them	646 participants from >40 (mostly European) countries	The in-person conference generated a total of 322 tons of CO_2 emissions (0.5 ton per participant) if all traveled by plane, amounting to 5% of annual per capita emissions in Europe	Not applicable

Table 2. Suggestions and corresponding examples/ rationale to organize eco-friendly and inclusive conferences based on the 11 included articles [in brackets].

Suggestions	Examples/ Rationale
For in-person conferences	
Choose the most accessible venue for an in-person conference based on the geographical locations of target attendees [12,27,30,33]	Choose a more central location with good access to railroad networks Low-carbon alternatives to air travel: trains, buses, carpools Rotate conference venues among different geographical regions, especially of recurring events of similar attendance
Reduce frequency of large in-person conferences [30,33]	Conduct biennial rather than annual in-person meetings, or reduce the number of large meetings to at most one per year
Organize joint in-person conferences [33]	National, international, and/or regional organizations can collaborate to merge their annual conferences
Consider emission profile of delegate travel [26,30,33]	Conference hubs can reduce long-distance flights If able, compute the travel footprint of a large set of travels and identify a venue with minimum overall carbon emission Consider asking pertinent information (e.g., city and country of origin; transportation means) to estimate carbon footprint in the online registration form
Monitor and minimize the carbon output of professional activities [26,31]	Prioritize attendees with only small carbon footprints in in-person conferences
Avoid single-use items [12,30]	Require electronic instead of physical posters; re-evaluate use of booklets, lanyards, plastic water bottles, coffee cups, and other conference items
Offer delegates the option of carbon offsetting [12,26]	To provide opportunity to invest in renewable energy and earth-friendly projects (e.g., tree planting)
Consider emissions from other sources like food, accommodation, and tourism [12,26]	Re-evaluate emissions from hospitality and food service industries at the conference site
Conduct strategic planning virtually instead of in-person [30]	Organizing committees can meet virtually through videoconferences
Maximize the travel impact of all participants [30]	Organize topical meetings next to plenary sessions to cover a full week for instance Avoid short-duration, single-goal in-person meetings
Keep carbon dioxide emissions of consortium meetings around 100 tons [27,30]	May opt to limit attendance to key persons whose presence is mandatory, but sweeping the locations across the entire consortium by changing venues
Limit the number of attendees [27,30]	May prioritize the youngest members to present their work, exchange fresh ideas, and network in-person Limit participants to those coming from within the region or continent
Promote public transport [27]	To reduce carbon emissions without directly conflicting with the objectives of academic international conferences
Increase awareness of attendees on carbon footprint-reducing habits and their benefits [27]	Provide specific and practical environment conservation techniques (e.g., through electronic infographics, conference reminders, perks, assistance in booking train tickets, discount vouchers from train companies, personalized carbon footprint computation) Compute the conference's total carbon footprint, publish findings on the website, and share them with each individual delegate
For online or hybrid conferences	
Whenever possible, organize virtual rather than in-person conferences [10,12,26,30–32]	Virtual conferences, webinars, online lecture series, and other synchronous and asynchronous methods to disseminate conference content and interact with experts, colleagues, and like-minded attendees
Do more than virtually replicate in-person conference [33]	Text-based online forums to allow discussions beyond end of conference
Archive virtual content and make it open access [33]	To increase reach and accessibility

Make registration fees affordable [33] or free for online conferences [31]	To increase attendance and foster equity
Decentralize a large conference with multiple small venues (hub and spokes) [29–31,33]	A single global hybrid (in-person and online) conference can take place simultaneously in different hubs linked virtually so that attendees travel only to their nearest hub
Offer platforms for both low- and high-bandwidth Internet connections [12,33]	Uploaded recordings instead of live sessions
Reallocate conference funding [33]	Invest in virtual technologies, technical support, and social media engagement
Allow conference leave [33]	To permit uninterrupted virtual participation
Alternate in-person and virtual conferences [29]	To reduce in-person meetings and their corresponding carbon emissions from travels
Offer a hybrid (in-person/ virtual) conference [29]	To reduce in-person meetings and their corresponding carbon emissions from travels
Select appropriate platform/s based on available financial and technological support capacity [10,32]	Zoom or Crowdcast can be used for live-streaming content; YouTube for sharing recorded videos and building a digital archive; Wix built-in tools and Mailchimp for creating a mailing list; Facebook, Instagram, Twitter for promoting an event
Provide attendees with a chance to virtually meet and chat with like-minded experts one-on-one [10]	Algorithmically matching attendees to speakers based on their research abstracts to improve the social experience of virtual attendees and resemble an in-person conference
Build an online community of practice [28]	A group of volunteer researchers and public health professionals that can meet regularly through videoconferencing and organize webinars to facilitate information exchange and dissemination among people with diverse backgrounds