Evaluating features of scientific conferences: A call for improvements

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Abstract
Scientific conferences provide valuable opportunities for researchers across career stages and disciplines to present their latest work and to network with their peers. The advent of the internet has opened new possibilities for interaction, collaboration and networking, yet the uptake of tools enabling remote participation at scientific meetings has been slow. Academic conferences have become more international with high proliferation in the number of meetings and attendees, but the format and quality of their organization lags behind what is possible. As a result, the experience of attending conferences in many disciplines today is not appreciably different in many respects. A few conferences in some disciplines have recently implemented valuable changes for the community and have become more receptive to attendees with families. Many meetings could still be improved significantly in terms of diversity, inclusivity, promoting early career researcher (ECR) networking and career development, venue accessibility, and more importantly, reducing the meetings' carbon footprint. These issues are openly visible and to some extent discussed among researchers on social media. It is important to accelerate and mandate these efforts so that researchers in all disciplines, in particular ECRs, consistently benefit from scientific gatherings, for years to come. We examined the current state of over 200 national and international academic meetings in various disciplines for key features of inclusivity and sustainability and propose solutions to make conferences more modern, effective, equitable and intellectually productive for the research community and environmentally sustainable for our planet.

"They always say time changes things, but you actually have to change them yourself."

— Andy Warhol

Introduction

Scientific conferences provide a platform for researchers to share and discuss research findings, exchange ideas and insights, and network for career development. Organizing inclusive and useful scientific meetings is a service to the research community and requires passion, dedication, considerable time and thoughtful planning. While the size of the scientific workforce and the number of national and international conferences has increased dramatically globally in most scientific disciplines (1–4), opportunities to travel to present research at these meetings are still not available to many researchers (5–7). After over 180 years, most conferences are held in person, are too cost-prohibitive to attend and not geographically accessible for many researchers, particularly researchers from young labs, low to middle income countries and junior principal investigators (PIs) (Figures 1, S1) (8). Furthermore, despite the exhausting travel, the experience of presenting at meetings for early career researchers (ECRs) and minorities who attend has not improved appreciably (9–11). Several large conferences have implemented community-oriented sessions supporting more diverse groups of attendees (8). Owing to the increasing number and size of scientific meetings, conferences held in person also contribute to rising atmospheric carbon dioxide (CO_2) levels and thus to climate change, which has implications for the research community and beyond. Scientific conferences generate multi-billion dollar expenditures (12,13), feeding business ecosystems that prey on national and international research and development budgets. The events industry describes billion dollar activity, but beyond personal value to some participants, the external value of conferences in their current format for the scientific community is seldom measurable. There is a need to discuss whether the status quo of academic meetings and resource allocation is efficient, equitable and environmentally sustainable. When it comes to improving conferences, the question is not "is it possible?" but rather "are we as scientists willing to do it before we have run out of options?". Here we examine 232 academic conferences in various disciplines for their offered features, highlight key ongoing issues (8)(Figures 1-2, Tables S2-S11) and discuss a set of key considerations and steps to improve these gatherings.

The current state of academic conferences: Lack of equity, inclusivity and environmental sustainability

Equity in planning scientific meetings creates fair opportunities for all and inclusivity creates a welcoming environment for all participants. The current organization of many conferences leads to practices that exclude researchers on a wide range of factors including, but not limited to, gender, ethnic, socioeconomic, health and geographical backgrounds, and career stage (8). Women and researchers from racial and ethnic groups, who are under-represented in various fields, are the least likely to be offered opportunities to speak at meetings in their discipline (14,15). In-person conferences also harm the planet (Figures 1-2, Tables S2-S11)(8).

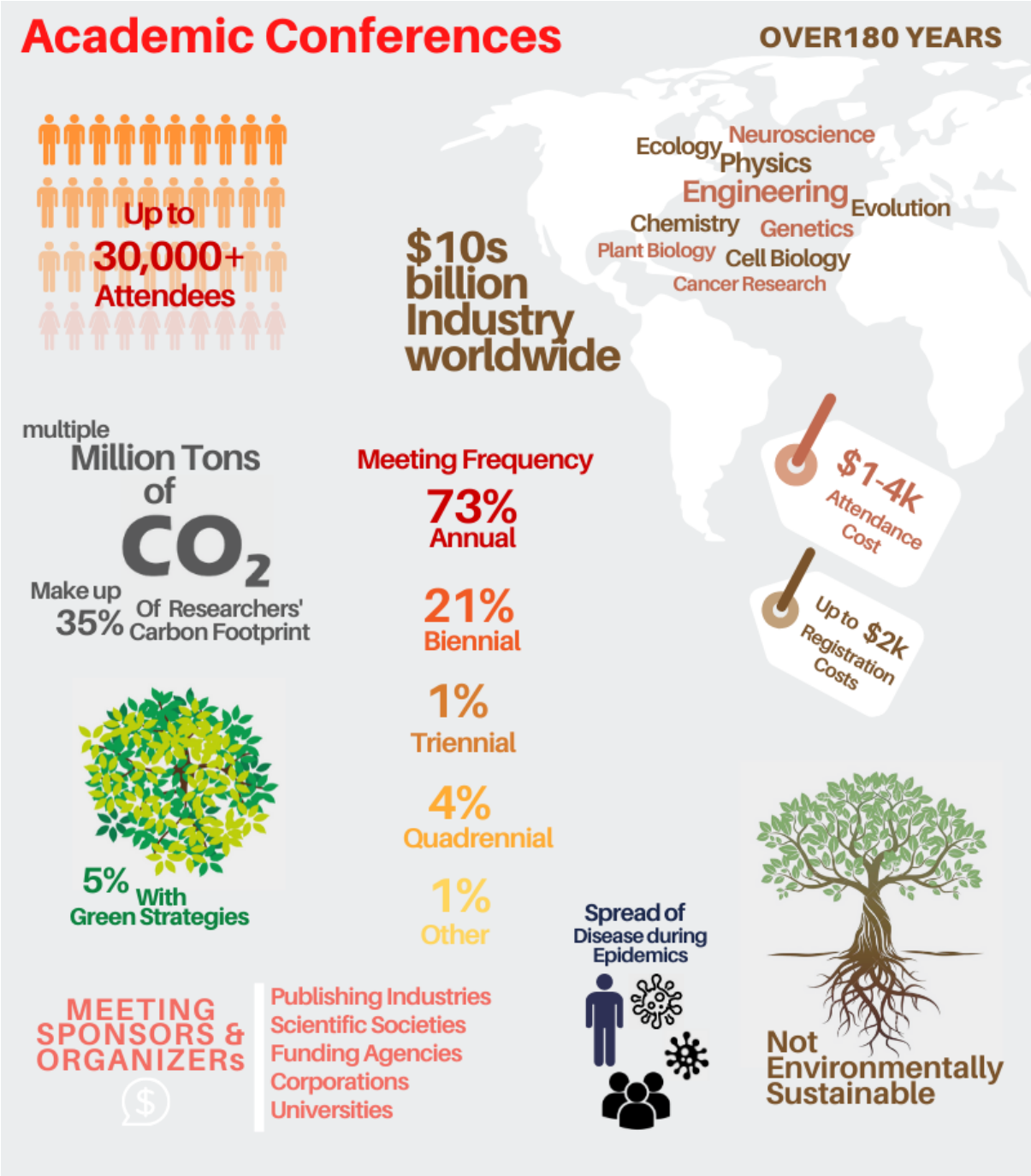

Figure 1. Academic conferences are not environmentally sustainable. Summary of analysis of 232 recently held conferences (2018-2020) in various scientific fields including Engineering, Physics, Mathematics, Neuroscience, Genomics, Chemistry, Ecology, Evolution, Cell Biology and Immunology (8) (Tables S2-S11). 1% of these meetings were held multiple times a year, 73% were held annually, 21% were held biennially and only 1% and 4% were held triennially and quadrennially respectively. Registration fees varied from US$100 to up to $2,000. Only 5% of conferences included any form of green policy. Number of attendees reached up to over 30,000 for a single event. A total of ~766,000 attendees of these conferences collectively spent over US$1.1 billion and generated ~2 million tons of CO_2 in the form of air travel and other activities to attend these meetings (Table S6,7,8) (8).

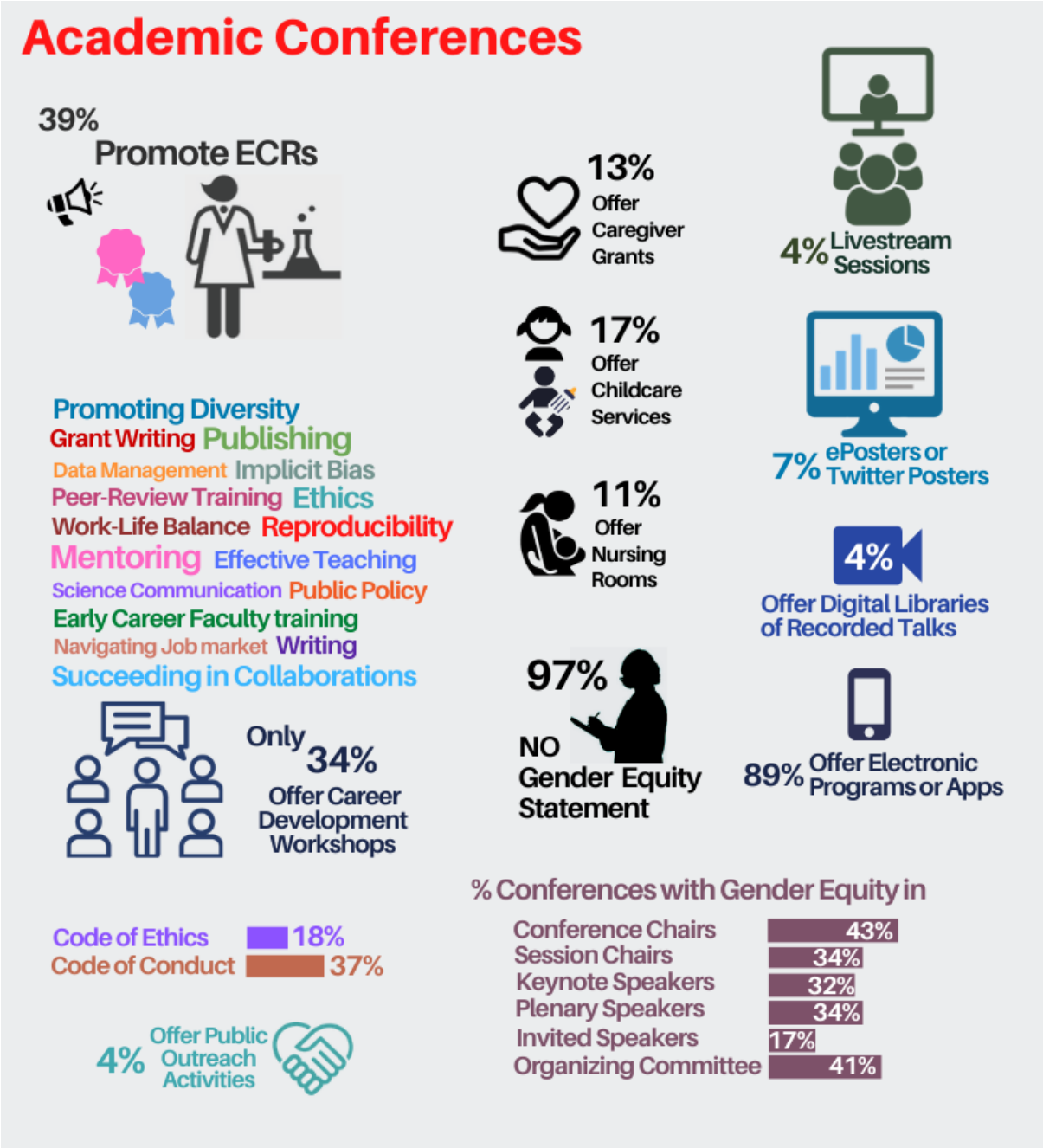

Figure 2. The majority of academic conferences are not modern, equitable or inclusive. Summary of analysis on 232 recently held conferences (2018-2020) in various scientific fields (8) (Tables S2-S10). 97% of conferences did not provide a gender equity or diversity statement and did not disclose their attendee gender statistics on their website. 32% of conferences with information available online had keynote speaker gender balance, 34% of conferences with information on plenary speakers and 17% of conferences with information on invited/featured speakers achieved a 50% or higher participation of women speakers. 41% of conferences that reported information on their website achieved organizing committee gender parity. 43% of conferences reporting conference chair names and 34% of conferences reporting session chair names achieved gender equity. Only 37% and 18% of conferences we examined included a code of conduct and code of research ethics or research integrity on their website respectively. Only 34% included career development workshops for ECRs and 39% included promotion events such as (either) special symposiums or podium talks or awards for ECRs (Early Career Researchers) only (Table S9) (8).

The alarming carbon cost of scientific travel

The aviation industry is responsible for over 860 million metric tons of CO_2 emissions every year, with every metric ton of CO_2 emitted leading to 3 square meters of Arctic sea ice loss (16). Global aviation as a country ranks among the top 10 emitters (17). With an upward of 2,500 flights a day over the north Atlantic, transatlantic flights are the third largest contributors to annual global CO_2 emissions (18). Conference attendance represents 35% of a researcher's footprint (19). In hosting hundreds to thousands of researchers, conferences produce substantial air travel related CO_2 emissions (Figure 3, comparable to the global annual per capita CO_2 emissions in many countries, Figure S3) and large amounts of other waste in the form of promotional items (Box 1). The number of attendees varies from 100 to over 30,000 for a single event (Tables S1, S6) (8), and most conferences (73%, 170/232 in our database) are held annually (Table S4). This means that the average three-day, 1,000-person national conference generates over 580 tons of planet-warming CO_2 emissions, every year. Hence, the current size and ever-increasing number of scientific meetings is of grave environmental concern (Figure 3, Table S1).

With the current career norms, researchers are expected to fly nationally and internationally, often several times a year, for scientific conferences, which adds up to a significant amount of emissions. A single researcher's flight from the United States to Europe and back to attend a conference will generate over 1,000 kg of CO_2. There are 57 countries where the average person produces less CO_2 in a year (20) (Figures 3, S3). Air travel by 6,741 attendees to and from a single meeting of the American Association of Geographers in Seattle produced ~16,000 metric tons of CO_2, equivalent to the amount that 53,500 people living in Haiti generated during 2014 (21,22). The total carbon footprint from a single annual meeting of the Society for Neuroscience, hosting 31,000 attendees, is equivalent to the annual carbon footprint of 1000 medium-sized laboratories (23). In addition, each night spent in a hotel creates over 70 lbs of CO_2 from fossil fuel derived electricity. Multiplying these amounts of CO_2 generated by the hundreds and thousands attending a single conference (Table S1) (8,24), shows why curbing emissions through diminishing scientific air travel must become a priority for every researcher, university, scientific society and funding agency.

The overwhelming majority of conferences are not environmentally sustainable and lack clear green strategies or climate policies (8,25,26). Only 5% (11/232) of conferences we examined offered some form of sustainability initiative incorporated into their organization (Figure 1, Table 9). A total of ~766,601 attendees of these conferences collectively generated ~2 million tons of CO_2 in the form of air travel and other activities to attend these meetings (8). Climate change has already shown devastating consequences; extreme weather events; the spread of viral and bacterial disease; rising sea levels; increased food insecurity; billions of dollars in financial costs for a single nation; and slowing of scientific progress among many others and these are only early impacts (27,28). According to the 2019 UN climate report, CO_2 emissions must drastically decrease within a decade in order to slow down the global temperature rise and irreversible climate catastrophe (29,30). This means that time is against us and small changes in work organization and lifestyle will not be sufficient any more. There are over 8.4 million full-time equivalent researchers in the world as of 2015, representing a growth of over 20% since 2007 (31,32). Clearly, researchers can contribute to these goals by reducing their travel related CO_2 emissions.

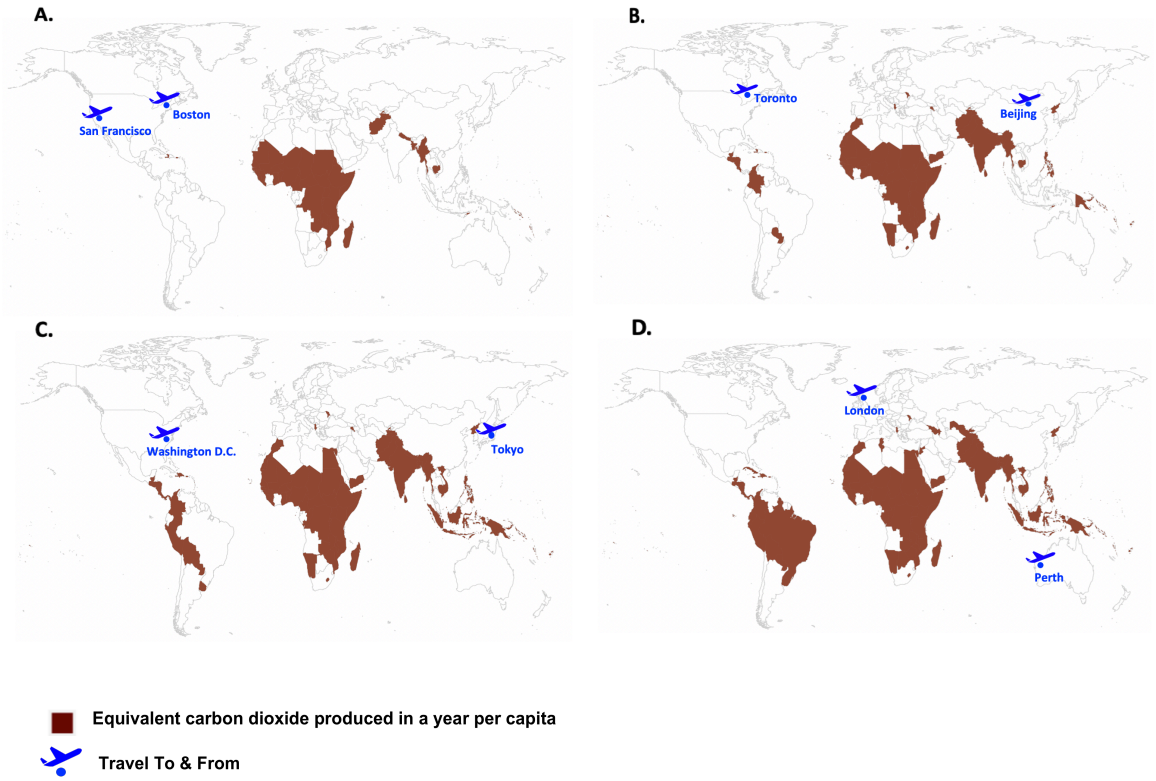

Figure 3. In-person conferences leave a large carbon footprint. The air travel of a *single* attendee emits as much CO_2 as many people do in a year. Even short-haul and domestic flights produce large amounts of CO_2. A) Flying from Boston, Massachusetts to San Francisco, California and back for an annual American Biophysical Society (BPS) conference generates about 623 kg (0.69 tons) of CO_2. There are 47 countries where the average person produces less CO_2 in a year (shown in color here). B) Flying from Beijing, China to Toronto, Canada and back for a Society for Neuroscience (SfN) meeting generates about 1,621 kg (1.79 tons) of CO_2. There are 84 countries where the average person produces less CO_2 in a year (shown in color here). C) Flying from Tokyo, Japan to Washington D.C, United States and back to attend an annual American Association for Cancer Research (AACR) conference generates about 2,144 kg (2.36 tons) of CO_2. There are 91 countries where the average person produces less CO_2 in a year (shown in color here). D) Flying from Perth, Australia to London, United Kingdom and back for Virology & Infectious Diseases (ICVID) 2019 generates about 3,153 kg (3.47 tons) of CO_2. There are 109 countries where the average person produces less CO_2 in a year (shown in color here) (Data Source (33), Carbon Footprint Calculator (34). Comparable to global annual per capita CO_2 emissions in many countries, Figure S3.

The cost of opportunity is prohibitively high for ECRs

The costs associated with attending conferences include meeting registration fees, airfares, accommodation, ground transportation, food and event tickets. The registration fees alone often range from a few hundred to over a thousand US dollars (8). The total cost of attending large national scientific meetings in the United States is ~US$1,000-$2,000, equivalent to one or more months of graduate and postdoctoral researcher net salary worldwide (Figure S1) (8,35,36). As a result, a principal investigator may attend multiple conferences a year but will have to budget over ten thousand dollars to send multiple trainees to one conference per year. The costs of attending international conferences are well in excess of national and regional meetings (~US$2,000-$4,000) (31). A plane ticket constitutes a substantial cost for international conferences. Trainees often have to cover the expenses upfront and on their own as travel awards are scarce and typically only a limited number are offered by the meeting organizers, universities and non-profit organizations; these awards often barely cover the bulk

of conference attendance costs, which include travel, food, and board expenses (Table S9) (8,37,38).

The rich getting richer disproportionately harms ECRs

Attendance expenses may not appear burdensome to wealthy participants from select academic labs in developed nations but are unaffordable for many academic research labs worldwide. Even tenured academics can struggle to afford conference participation. The less wealthy subsidize the expenses of the speakers, who usually attend scientific meetings free of charge. Bursaries or reduced rates for some participants do not provide a convincing justification for why speakers, who often comprise the most well-off academics, should have their expenses paid for by other conference participants. Even if all trainees attended free of charge, other non-keynote academic participants then may have to pay their way for the sessions. Attaining travel funds is more difficult during early career stages, and this is aggravated by funding structures and researchers' lack of financial stability especially in nations of low-income economies. Researchers in these countries are often unable to attend national or international meetings (minimum wage globally shown in Figure S1) unless they are invited or manage to acquire travel grants. Furthermore, the research budget for many laboratories can be limited so that even in the rare occasions that ECRs obtain funding, they would privilege its use for research instead of traveling, as few laboratories may be able to afford both. Hence, conferences are even more restrictive to participants from lower income labs and countries.

Obtaining a travel visa is challenging for many researchers

Obtaining short-term visas to travel to scientific meetings is a major hurdle for many researchers, particularly those from developing nations (7,39,40). A number of countries have explicitly stated that certain nationalities are not welcome, or will have to endure lengthy, uncertain and costly procedures to obtain a visa (7). Recent long-term conflicts and changes in the political climate at conference destinations (often major scientific hubs) have added to these challenges. Travel bans can also come into effect during national and global health emergencies such as epidemics and pandemics (41). These obstacles not only deeply affect the lives and careers of scientists working in developing countries, but also citizens of countries with visa restrictions who live and perform research in global scientific research centres planning to attend conferences elsewhere (Figures 4, S2).

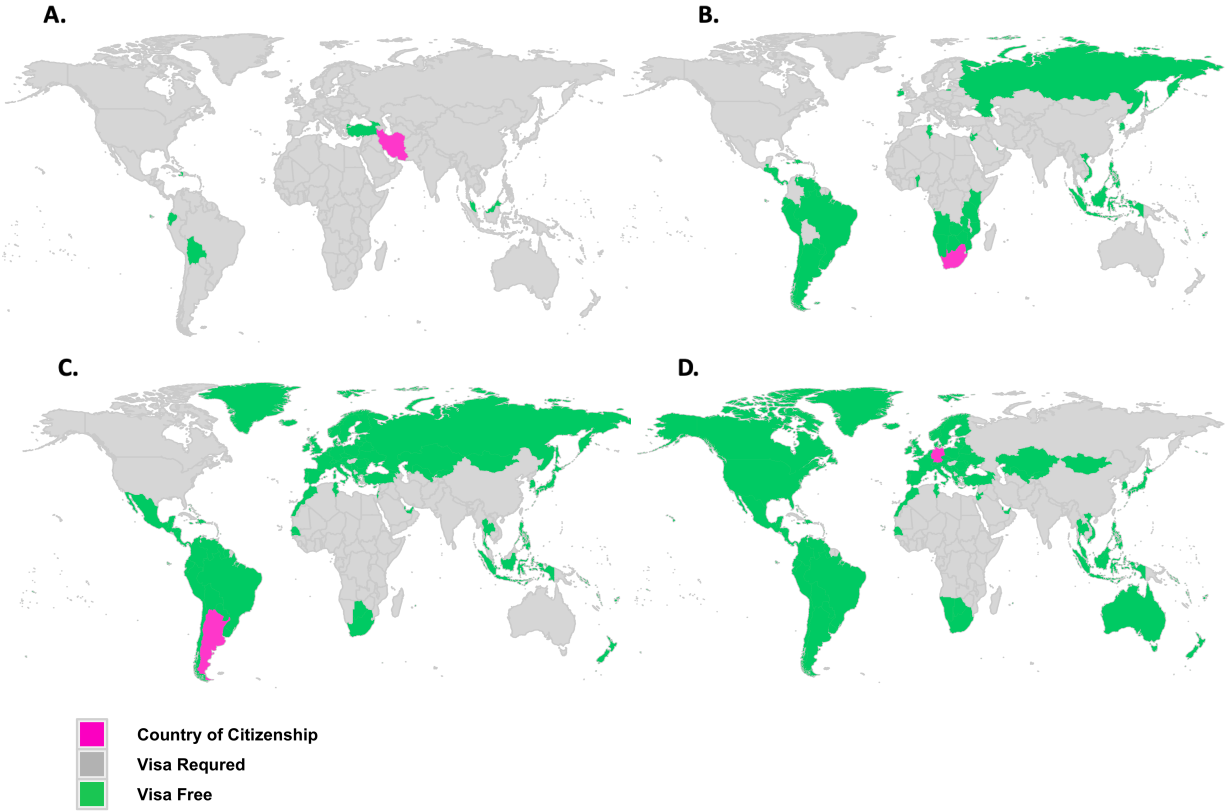

Figure 4. Visa restrictions limit scientific career development. Short-term visitor visa requirements for researchers who are citizens of A) Iran B) South Africa C) Argentina and D) Germany. Researchers who are citizens of these four countries (origin in pink) can only travel to select countries (in green) without applying for a visa for a short visit to attend a scientific conference (Data source (42)).

Conferences lack gender and career stage equity

Conferences in many disciplines lack participant diversity in terms of gender, ethnicity and other identity groups as chairs and speakers (8,10,43). 97% of 232 conferences that we examined lacked a statement of gender balance or diversity (Figure 2, Table S9) (8). In particular, women are underrepresented among conference and symposium session chairs, plenary or keynote speakers, invited lecturers, or as panelists in a broad range of academic meetings (8,44–46). In our examination of 232 conferences in various disciplines, out of the meetings reporting names of chairs, organizers and invited speakers online, only 43% and 34% of conferences achieved gender parity for conference chairs and session chairs respectively; 41% achieved gender parity for conference organizers or steering committees; 32% and 34% achieved gender parity for keynote and plenary speakers respectively and only 17% had equal numbers of male and female invited or featured speakers (Table S9, Figure 2). The process by which speakers are selected, including speakers chosen from abstracts submissions, can generally be improved by removing intended and unintended biases (47). The current lack of diversity hinders advancement in scholarship, and it is especially discouraging to junior researchers (48).

Ways to improve academic conferences

Science strives to contribute to the collective knowledge and the betterment of the human condition. Therefore, researchers must maintain consistency and responsibility in creating conditions to allow science to thrive, both socially and environmentally. Researchers should engage at the forefront of reducing CO_2 emissions to set an example for the global community. Elite cues can affect the scientific community and public opinion for changes in academic practices and lifestyle (17,39). Researchers need to strive to make conferences more inclusive and equitable with a combination of approaches that we describe here. Conferences in far-off vacation destinations are difficult to justify as these accumulate a large carbon footprint, often without a clear scientific objective and little to no benefit to the local scientific community. By altering the existing business model for conferences with a combination of concerted approaches that help organize equitable and nearly carbon-neutral conferences, a number of issues will be improved (Figure 1,2,6).

Replace in-person national and international meetings with more ground-based travel to regional meetings

Unlike long-distance flying which results in emissions of hundreds to thousands of kg of CO_2, ground-based transportation produces lower CO_2 emissions (Table S8). For example, traveling 40 miles to a regional conference results in emission of 20 kg of CO_2. Thus where feasible, public or shared transportation options such as the bus or train should be used instead of a car or plane (49). To reduce costs and travel carbon footprint, funding agencies and scientific societies need to fund and incentivize less frequent (for instance biennial) smaller regional meetings held by specialized scientific societies with only a few hundred attendees (e.g. American Physical Society regional meetings) in favor of large national and international ones which involve flying. The smaller size of these events enables attendees to interact and discuss science in ways that provide ECRs with ample opportunities to exchange ideas and meet established researchers. These meetings can be live streamed, recorded and made available globally via digital libraries for the benefit of other researchers. Furthermore, a number of small regional and virtual meetings can be funded by public and private research funders such as the UK Wellcome Trust or the US National Institutes of Health (NIH) and National Science Foundation (NSF) via designated grants (NIH R13/U13 or NSF RCN grants supporting scientific meetings) which conference chairs apply for in order to fund the meeting (50,51). Large conferences are often hosted in expensive cities as there are many accommodation options for large crowds, while conferences in more affordable locations are typically smaller in size. Regional society meetings can provide many benefits, such as low hosting costs. Conferences held in more economic and public venues, schools or university campuses, may also offer attendees the opportunity to visit local labs, tour facilities, and interact with the local scientific communities at the venue, potentially bringing benefit to the local community (Box 1).

Make research results more accessible globally via virtual access

Face-to-face interactions at conferences are important in generating new ideas, networks and collaborations. These interactions can be facilitated via digital conferencing that has made online face-to-face contact possible (Figure S4)(52–56). Reducing academic air travel does not impact professional success (57) and holding connected meetings across major continental centers around the world is feasible using online streaming and chat technologies which create more space for researchers to interact and connect. Multi-location conferences where participants only travel to a nearby location (online conference hub) and get to interact with other “local” scientists are also viable (58,59). These semi-virtual conferences can be distributed across locations on multiple continents. Each hub may hold its own in-person keynote and panel sessions, but the hubs can also be connected with each other for virtual panel sessions and discussions; this enables speakers to make remote presentations and

allows participants to upload electronic versions of posters. At the same time, the attendees' experience was clearly positive, showing that the multiple-site format can serve as an alternative to the traditional one-site format of holding national and international conferences (60). Live streaming provides many benefits including attendee chat amongst other online attendees in real time, access to sessions that work for attendee schedules, and the ability to stream sessions from any devices while on the go. The number of conferences that are streamed digitally or held in a virtual reality setting are limited - only 8% (18/232) of the conferences that we analysed provided digital talks, recorded talks or electronic posters - but these have increased over the past few years (Figure S4) (53,55,58,61–67), and many more are urgently needed in all disciplines. In the end, reducing one's physical conference attendance might make the remaining conferences more impactful and rewarding. A flow-on effect from making conferences virtually accessible, is that this will increase reach and access globally especially to researchers in disadvantaged economies. Currently, speakers spend time and resources preparing talks which end up reaching a limited audience with limited geographic impact that is often restricted to wealthy economies.

Foster digital networking by investing in relevant, immersive and interactive experiences

It is crucial for organizers of virtual conferences to develop strategies for facilitating digital connections. Fully streaming conferences (beyond video-conferencing select talks) can be made feasible without many significant additional resources, and can also be accompanied by online (e.g. Slack) discussions and successful Twitter (poster) conferences (68–71). Participants can also record and upload videos of their presentations that are posted to the conference website. During a several-week period when the conference is "open", attendees can watch the videos, ask questions, and interact with the speakers in online forums; graduate and postdoctoral positions can also be offered and applied for. iBiology (a project creating open-access science videos on biology research and science-related topics) has provided virtual talks and lectures for a number of years (72,73). The North American Vascular Biology Organization (NAVBO) holds a number of yearlong webinars, online journal clubs and online mini-symposia (74). A number of Slack groups have taken the initiative to connect researchers in life sciences related disciplines globally via online meetings and discussions (75). Conference attendees can form groups on Slack or similar platforms, hold their meetings online and keep connected virtually afterwards. Electronic (online) poster sessions can provide each presenter with the opportunity to tag their poster with a 3-5 minute talk summarising their work. Submitting video presentations of talks and posters which attendees could watch (76) followed by a 'direct message' to the authors/presenters for inquiries can be made feasible via an online platform. Scientific electronic panels can be held via platforms such as Virtual Keynote Symposia (VKS), Zoom, Vimeo livestream, OBS, ON24, Meet by Google, GoToWebinar and GoToMeeting, allowing both video conferencing and the opportunity to break into "breakout rooms" accommodating smaller discussion groups (e.g. via Slack or Discourse) (18,19,23,57,77,78). These platforms and others are being utilized for scientific chats on a daily and weekly basis where ideas are exchanged and collaborations are shaped among researchers (79,80). IEEE association offers tools such as WebEx (with recording option), Google Hangouts (no recording option), INXPO, and YouTube for online meetings and recordings and tools such as Camtasia, QuickTime and WebEx Recorder for offline recordings. A number of recent conferences to be held in-person in 2020, which were cancelled due to the COVID-19 pandemic, launched their meetings online using free Open Science Framework (OSF) Meetings instance to facilitate virtual dissemination of presentations and posters by their members and attendees (81). Digital conferences and discussion forums can, in fact, serve to assist communication between early career and senior researchers since writing a comment or question in a forum can feel less intimidating than approaching an established scholar in person. With more time to think the presentations through, attendees can put their best foot forward during interactions and networking with speakers.

Preprinting research outputs could reduce the number of all conferences

A recent survey carried out with participants of conferences in an entire research sector, revealed that only 2% of its 2,326 respondents found these meetings to be useful and cost-effective (82). 44% mentioned that these conferences had "no perceptible impacts" on their research projects, programmes or policies, while 26% found these conferences had been impactful, but not cost-effective. The conclusion from this data highlights the need for researchers to critically evaluate the necessity of holding a conference. Early dissemination of scientific findings can occur online via preprints. Preprints are written scientific products such as manuscripts uploaded by researchers to public servers such as arXiv, bioRxiv and OSFramework (83). Preprints may contain complete or in progress data and methodologies (i.e. the same manuscript being submitted to a journal). Preprints are used at an increasing rate in various fields and are already benefiting life scientists at large (84–87), but are underutilized and can be used in new ways to aid career development and increase the efficiency of scientific research (88,84). Widespread preprinting of research results can reduce the number of conferences held overall as researchers broaden their knowledge of the field and develop research ideas by learning on recent advancements months to years prior to publication of new results in journals. Through early dissemination of scientific findings, our planet, scientific advancement and researcher career development in all countries will benefit. Thanks to preprints, many investigators, especially in countries of lower-income economies, are now able to follow the most recent updates in their field. This also reduces the need to travel to discuss already published findings.

Preprinting can accompany and improve digital conferences

Additionally, there are a number of channels on preprint servers such as bioRxiv specific for preprinting conference proceedings, other preprint servers such as OSFramework can follow suit. In the case of digital conferences, all research materials such as abstracts, videos of talks and posters and presentation slides can be uploaded to Zenodo (with a Digital Object Identification or DOI) and protocols can be uploaded on protocols.io. Having all research products uploaded to a free open access online platform as part of a digital conference does not entail extra work and researchers can invite and review comments on site or via peer-review platforms such as PREreview (90,91). Researchers can also cite these outputs on their manuscripts and curriculum vitae. Digital libraries of abstracts, talks and poster presentations allow less privileged researchers unable to attend these meetings to discover the advances presented at those events in real time.

Box 1. Actions to Improve small and large conferences	
Hold meetings fully online or connect regional conference hubs digitally by livestreaming the conference	Use online platforms for your virtual academic meetings: Scientific electronic panels can be held via platforms such as Virtual Keynote Symposia (VKS), Zoom, YouTube streaming, Crowdcast, Vimeo livestream, OBS, ON24, Meet by Google, Google Hangout, GoToWebinar and GoToMeeting, or a combination of two of these platforms allowing both video conferencing and the opportunity to break into "breakout rooms" accommodating smaller discussion groups (e.g. via Slack or Discourse) (52,79,81,92–95). These platforms and others are being utilized for scientific chats on a daily and weekly basis where ideas are exchanged and collaborations are shaped among researchers (79,80).

	Other tools include WebEx (with recording option), Google Hangouts (no recording option), INXPO for online meetings and recordings and tools such as Camtasia, QuickTime and WebEx Recorder for offline recordings. For anonymous Q&A organizers can use platforms such as Slido (96). Good Example Conferences: *EBRS 2019 carbon reduced meeting, Neuromatch 2020 and POM 2020 meeting* (61,65,97).
Go Paperless: Stop printing meeting programs and announcements	Meeting program booklets can be accessed electronically using mobile phone applications online or offline (98) saving up to a few hundred thousand pages of paper at a single large conference. Printing program books of 200 pages each for 15,000 attendees of American Diabetes Association conferences results in use of 3 million pages of paper. 89% of the 232 academic conferences we analyzed provided complete (talks and abstracts) electronic program schedules or phone Apps (Table S9). Paper should be used minimally if at all at regional conferences and any paper used (e.g. for promotional material or signs) should be 100 percent recycled. Good Example Conferences: *Evolution 2020* meeting (98).
Eliminate conference souvenirs, merchandise, non-compostable name badges	Conference badges, bags and various other paraphernalia create large wastage and cost organizers and sponsors significant sums of money. Instead attendees can bring/reuse their own materials and take notes electronically on their portable devices. Organizers and sponsors of regional conferences can repurpose the cost of ordering souvenirs to create more early career researcher promotion events and training workshops. Seed paper conference name badges have recently been proposed (61). Lanyards and gift mugs can be made from re-usable or compostable material or cancelled all together (62). Good Example Conferences: *Evolution 2020* & *I Scientist 2019* meetings (98,99).
Choose environmentally responsible accommodation	Hotels can be designated to attendees if operated in an environmentally responsible manner. Additionally, hotels can be selected at locations near public transportation. Good Example Conferences: *Evolution 2020* meeting (98).
Choose sustainable food catering	Conference dining menu can improve by serving less meat, particularly beef and pork products and increasing relative representation of quality vegetarian and vegan options, prepared with locally sourced, in season, organic, and antibiotic/hormone free ingredients at the

	catered events. Good Example Conferences: *Evolution 2020* & *ISHPSSB 2019*.
Reduce plastic usage	Organizers can ask the attendees to bring their own reusable water bottle (and mug) and make several hydration points available. Waste can also be reduced by using compostable food service materials whenever possible. Disposable cups should not be provided during refreshment breaks and organizers should make an effort to push for reusable crockery via access to a kitchen, non-disposable (made of ceramic, washed and reused) dishware and cutlery when serving food is included in the program. Good Example Conferences: *Evolution 2020 & Gordon Research Conferences & I Scientist 2019 meeting* (98).
Include environmental clean-up events	Conference organizers can arrange for an environmental clean-up event as a social activity in the form of forest or beach walking clean up that can also serve as photo opportunities for conference social media, providing time for attendees to socialize and discuss science while helping the environment, simultaneously achieving multiple goals.
Organize public outreach activities for attendees	Only 4% of the conferences (6/232) included public outreach events (e.g. public lectures). A possible social activity that could build longer-lasting connections is reaching out to local schools and libraries so that researchers attending the conference can also give public lectures with a layperson version of their talk or poster and engage with the public (100). Good Example Conferences: *Ecology & Behaviour Conference 2019* (101).

Provide free and on-site nursing and childcare facilities	Free or on-site facilities to support special needs such as lactation rooms for nursing mothers (102), children's play rooms, day care and assistance for parents or other caregivers of children and infants are not available at all conferences, and when available are not always affordable or designed for the female users. Out of 232 conferences examined in our study, only 13% offered caregiver grants to parents, 17% provided any form of childcare and 11% offered a nursing room for mothers (Table S9). There has been inertia in setting up and implementing more family-friendly policies at scientific meetings (11,47). Lack of support and the complexities of arranging care can make travelling for conferences expensive and stressful for ECR parents who must choose to either miss out on the career opportunities of travel, or incur costs and significant personal stress to them and their family (9). Providing such utilities is completely feasible (102–105) and well within the interests of conference organizers, funders, scientific societies and attendees. Good Example Conferences: *Evolution 2020, I Scientist meeting* & *TAGC2020* meetings (106–108).
Generate meeting code of conduct	Only 24% of 195 biology conferences held in North America and 37% of 232 conferences in multiple fields globally included in a recent study had code of conduct (8). Larger and national conferences were more likely to have codes than international or smaller ones - emphasizing the need for increased efforts in order to improve inclusivity and diversity and reduce the loss of (historically) marginalized scientists (109). Scientific societies, funding agencies and conference organizers should publish a code of conduct upfront for all participants to sign during conference registration and abstract submission processes and strictly enforce the policy. One comprehensive code of conduct has been designed by the R Foundation intended to be used for all R conferences (110–112). Good Example Conferences: *Molecular Biosystems Conference* (59).
Generate meeting code of Ethics	Only 18% of the 232 conferences we examined in our database offered a code of research ethics for attendees on the meeting website or associated scientific society website (Table S9). Good Example Conferences: Society for Ethnobiology meeting 2019, Society for American Archaeology meeting (113,114).

Improve attendee safety	Not all conference locations are safe for attendees, especially for women (115). None of the 232 conferences provided a safety mobile phone app, and only 2% provided safety instructions sheets for attendees. Potential solutions to this issue range from researching the location for the meeting, and mandatory safety apps (116) to a buddy system where attendees accompany or warn each other of potential dangerous circumstances, protect each other and report any issues that jeopardizes their safety. Meeting organizers must also take steps to eliminate potential threats to attendees by choosing safe accommodation locations, safe and affordable transportation modes, put forward anti-harassment policies and establish a clear system for reporting and handling such issues when they arise. Creating safer academic meetings can be helped with less emphasis on alcohol focused events. Smaller and regional conferences can enable attendees to look out for one another. Good Example Conferences: *Evolution 2020* meeting (116).
Organize well-planned networking activities	Scientific meetings must implement well-thought out and well-planned networking events (e.g. ice-breakers) to introduce trainees and established researchers to each other. Only 39% of the conferences we examined in this study offered some form of ECR promotion event (Tables S9-S10). More social events without alcohol can be planned with a focus on the events that would connect researchers across career stages within and across disciplines. Researchers can be randomly seated together in regional conferences or assigned to breakout rooms during virtual conferences and tasked with coming up with an idea for a collaboration in a project planning workshop or seek mentorship. Good Example Conferences: The *EMBO/EMBL "Seeing is Believing" 2019* & *TAGC2020* meetings.
A central database of scientific conferences	Conferences are often not well-characterized, evaluated or advertised within and across disciplines and countries; making it difficult and time-consuming for researchers worldwide, in particular ECRs, to identify the most beneficial gatherings. A central database in life sciences, engineering and associated fields can help keep researchers well-informed on the past and future meetings and the key considerations of environmental sustainability and equity that all scientific conferences must possess (8).

Incentives and mandates to support and promote low-carbon research careers

Business-related air travel by academics at universities continues to grow, increasing by 33% at a single institution in the last decade, reaching over 75,000,000 miles flown by their academics in one year (117). Greenhouse gas emissions caused by business trips can make up 60% of the total university greenhouse gas emissions with air travel responsible for up to 94% of the institutional travel-related emissions (118). Institutional practices should shift to mandate severe reductions in academic air travel as these changes will significantly reduce the academic carbon footprint. As researchers re-evaluate their practices, it is essential that other key stakeholders such as academic associations, scientific societies and funding agencies coordinate and mandate funding to only organize academic conferences in ways that require less flying. At many institutions and disciplines, scholars are granted tenure and promotions based in part on the number of research presentations they make at professional conferences (119–122). Furthermore, as postdoctoral and tenure-track jobs are scarce in many academic disciplines, ECRs face mounting pressure to attend conferences in order to network with potential colleagues. Changes can also be expected in funding and promotion requirements so that tenure-track academics do not have to choose between delivering an international talk and receiving a grant or tenure promotion. This will in turn encourage a culture of academic research that is less reliant on traveling. A number of research institutions and funders have implemented a carbon tax on air travel emissions caused by academic flying (77,78); some institutions have made it compulsory to travel by train rather than plane if the travel is less than 4-5 hours by train (123). Funds from a carbon tax can also be used to fund research that could fight against the climate crisis (117) and attendees and organizations can be required to plant trees if they attend a conference in person. Although institutions can estimate total emissions and buy offsets (for example paying for renewable energy or other programs designed to reduce emissions) (117), the climate impact of researchers flying are irreversible (124,125). Regional conferences and digital or virtual conferences are however more effective environmentally sustainable solutions in reducing the frequency of academic air travel compared to carbon offsets (60).

Create intersectionality and career stage equity at regional and digital conferences

A conscious effort must be made by the organizers of every single conference to maintain fair representation and inclusion as overcoming such biases involves not just awareness but positive action (126). Unreasonable excuses for lack of diversity such as “there are not enough women in a field” are no longer acceptable, given recent increases of minority scientists in many scientific fields across graduate, postdoctoral and faculty career stages (15,127,128). The gender breakdown of the speakers and session chairs could reflect the actual attendance breakdown. Only 3% (8/232) of recently held conferences published a statement of gender equity and actually achieved 50-50% balance of male and female speakers (Table S9) (8). Maintaining gender balance impacts both speakers and ECRs, who need to see representation and role models of their own gender in their field. Without clear guidelines and targets, excuses will always be made (and are actually made) to the point people claim there are no available speakers, but oftentimes not all avenues for seeking female speakers were explored (43). There are multiple online, open access databases listing women and LGBTQIA ECR trainees and faculty which can be utilized for selection of conference speakers (129,130). Blinding the selection of talks, removing conflicts of interest and having fewer long talks to make time for more short talks may all help ensure that minority groups of scientists are welcomed and equally represented in conferences (131). It is also important for conference organisers to be held accountable by the funding bodies in charge to achieve specific percentages of female speakers (132). Funders and meeting organizers need to pledge and enforce gender equity policies and public inclusion declarations and guidelines, make use of databases listing researchers of all backgrounds and publish the names of invited speakers and session chairs in advance of the conference program (129,133,134). Conference attendees can express conditional attendance, lifted only after the invitation of men and

women speakers in a fair and balanced manner (9). In a number of fields such as Ecology, multiple (but not all) conferences are yielding towards achieving gender equality for speakers and chairs; aiming beyond existing representation at the PI level. The number of ECRs has increased globally, and a number of talks can be allocated to early and mid-career researchers. PIs can nominate an ECR trainee or recommend an ECR faculty in their place to attend the conference. Similar guidelines can be adopted for the selection of session chairs and audience members volunteering to ask questions after talks.

Sponsor and promote trainee and ECR PI Career Development

Conferences are an optimal setting for diversity events, academic and non-academic job search training, training in strengthening collaborations, scientific communication, scientific writing, reproducibility, career development teaching and mentoring workshops. Only 34% of the 232 recently held academic conferences we examined offered some form of career development workshop with only a minority 7% (17/232) including mentorship workshops (Table S10) (8,135). The "Reproducibility for Everyone" group of the eLife community ambassadors (136) has pioneered reproducibility workshops at a number of conferences. There are few, if any, advocacy events such as feature talks and poster sessions for up-and-coming ECRs (e.g. postdoctoral fellows going on academic or industry job market or ECR PIs in the midst of their endeavors in their own labs). Among the conferences we examined, only 39% included ECR promotion events such as either special symposia or awards (Table S11) (8). Women and minorities are especially lacking in support, sponsorship and advocacy; hence, they miss out on numerous opportunities. A gender disparity in participation during discussions exists (137) as discussion and Q&A sessions are most often led by professors, i.e. session chairs prefer to pick professors to ask questions over students. This needs to change. Every session can be chaired by at least one ECR and have at least one ECR organizing the Q&A discussions. Trainees may also not volunteer to ask a question, which can be a daunting task. A good policy can be to specifically ask for a question from a trainee, or, if the talk is streamed online, to take the first question from the internet using platforms such as Slido that allow audience interactions (96).

Benefits of the proposed improvements to Research and Research Culture

Digital conferences are environmentally sustainable

Participation in the 232 national and international conferences held during 2018-2020 that we examined in this work, released over 1.5 million tons of CO_2 into the atmosphere (Table S8) (8). Only 5% of the global population enjoy the privilege of flying annually and most academics are in that demographic. A number of scholars routinely fly over 100,000 miles every year (138). Academic air travel makes up almost half of total university emissions (117,123). Air travel by an academic in the UK who on average attends only one international conference or meeting per year by plane, will produce CO_2 emissions footprint of about five tons. This is over ten times as much as the average UK person's carbon footprint from leisure flights, and nearly 20% more than the average UK citizen's total annual carbon footprint from travel and home energy combined (139). There are other damaging aspects of conferences which include plastic badges, bottles and other promotional items (Box 1). Reducing air travel to national and international conferences and organizing virtual conferences will have a dramatic impact on the environment. For example, a recent experience with multi-site conferencing showed reductions of 50%-70% in travel-related greenhouse gas emissions compared to the single-site alternatives despite the increased numbers of participants (60,140). Low-cost or free nearly carbon neutral conference models and online poster presentation practices will greatly reduce scientific conference air travel footprint (70,71,141,142).

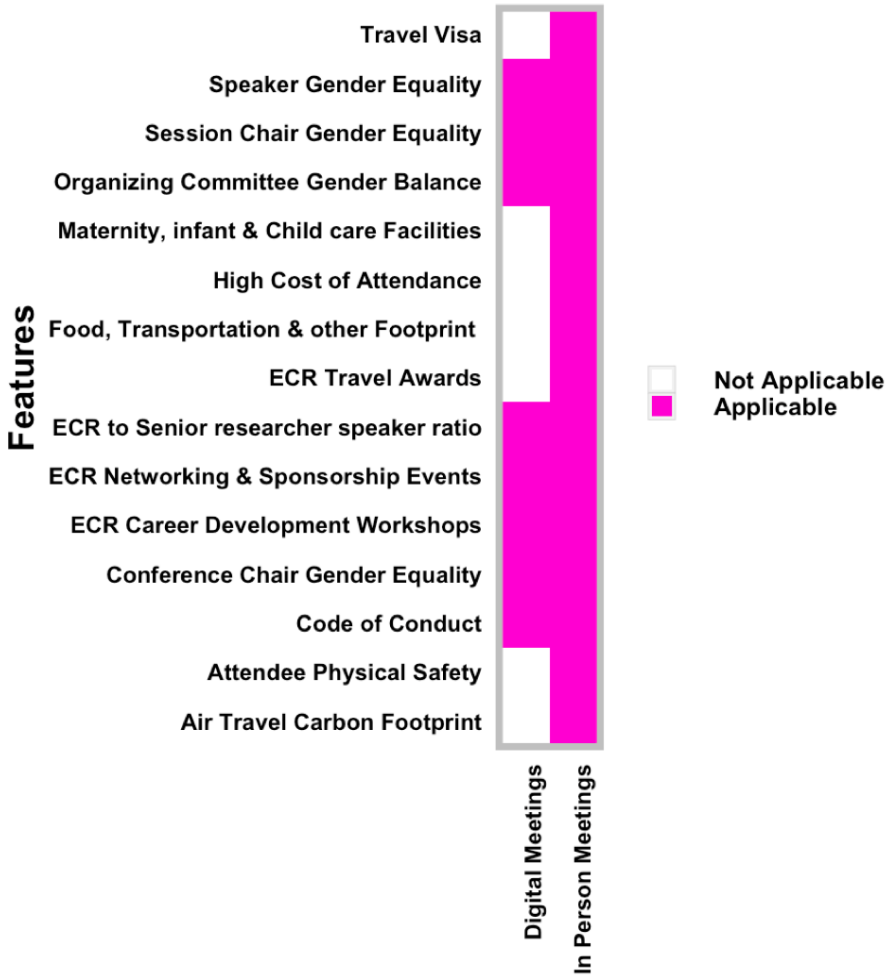

Figure 5. Digital scientific meetings present many advantages for the diverse scientific community. A visa (travel permit), travel carbon footprint, early career researcher (ECR) travel awards, In person attendance costs such as flying, accommodation, transportation and meals, childcare and infant nursing facilities and attendee safety are not applicable considerations to digital (online) conferences. Virtual conferences do not require catering, venue rental, or on-the-ground logistics coordination, they are substantially less expensive to put on than fly-in/in-person conferences. ECR: Early Career Researcher.

Digital conferences return funds to researchers

The global market size for all academic meetings and events is currently estimated at US$11.5 billion per year, growing annually (31). The cost of a recent academic conference of 20,000 attendees in Mexico reached over US$190 million (82). A total of ~766,601 attendees of the 232 conferences we examined, collectively spent over US$1 billion during 2018-2020 to attend these meetings (with a total attendance cost average at US$1500 per attendee) (8). This is over 3.5% of the NIH total annual budget. Conference organizing has become a global industry, generating income to a range of commercial or society conference organizers; travel, hotel and catering industries; and local tourist attractions that have little interest in inclusivity or the academic content being discussed. Researchers who attend, expect many benefits, such as diverse early career researcher training sessions or finding their next collaborator, but most conferences have never been evaluated for their actual impact on their field. A fraction of research funds used to cover attendance of in person conferences can be devoted to

establishing digital facilities at universities and other research institutions so that scientists globally can attend meetings online. These resources do not require large funds and will be of benefit to the researchers and institutions that invest in them, long after the conferences have ended. This will also shift the economic benefits a handful of corporations enjoy to local research laboratories and sustainable economies as most conferences become regional with digital broadcasting to hubs nationally and around the world. Eliminating the megaconference bubble and its ballooning costs will return funds to research labs and enable more trainees and underrepresented minorities to attend and exchange their ideas, democratizing access to knowledge and accelerating innovation.

Digital conferences are more inclusive

Fly-in conferences may meet the needs of some academics and professionals in wealthy countries but researchers with family commitments, physical or health limitations and vulnerabilities can not easily attend these conferences. Digital conferences incur lowest costs and present many benefits (Figure 5). Digital conferences are organized when travel is not possible due to disease outbreaks such as the recent COVID-19 pandemic (Figure S4) (41,63,66,67,143). In addition to the added socio-economic and ethnic diversity, digital conferencing can increase diversity of the career stages and genders of attendees, which in turn improves the quality of the scientific research and the conferences (144). Currently, graduate and postdoctoral trainees on average produce about three times less emissions from air travel than fully tenured professors, and female academics also travel less than their male colleagues (26,145). In addition, a growing body of researchers from diverse nationalities and backgrounds face difficulties in obtaining funds and travel permits to attend conferences. Addressing these challenges needs a will from scientific societies to be truly international. Hosting conferences digitally, as has recently been done in a few fields successfully, is a truly inclusive and environmentally sustainable solution (58,64). This can boost the number of registered participants up to 50% compared to previous comparable conferences, as observed by a recent semi-digital conference (140).

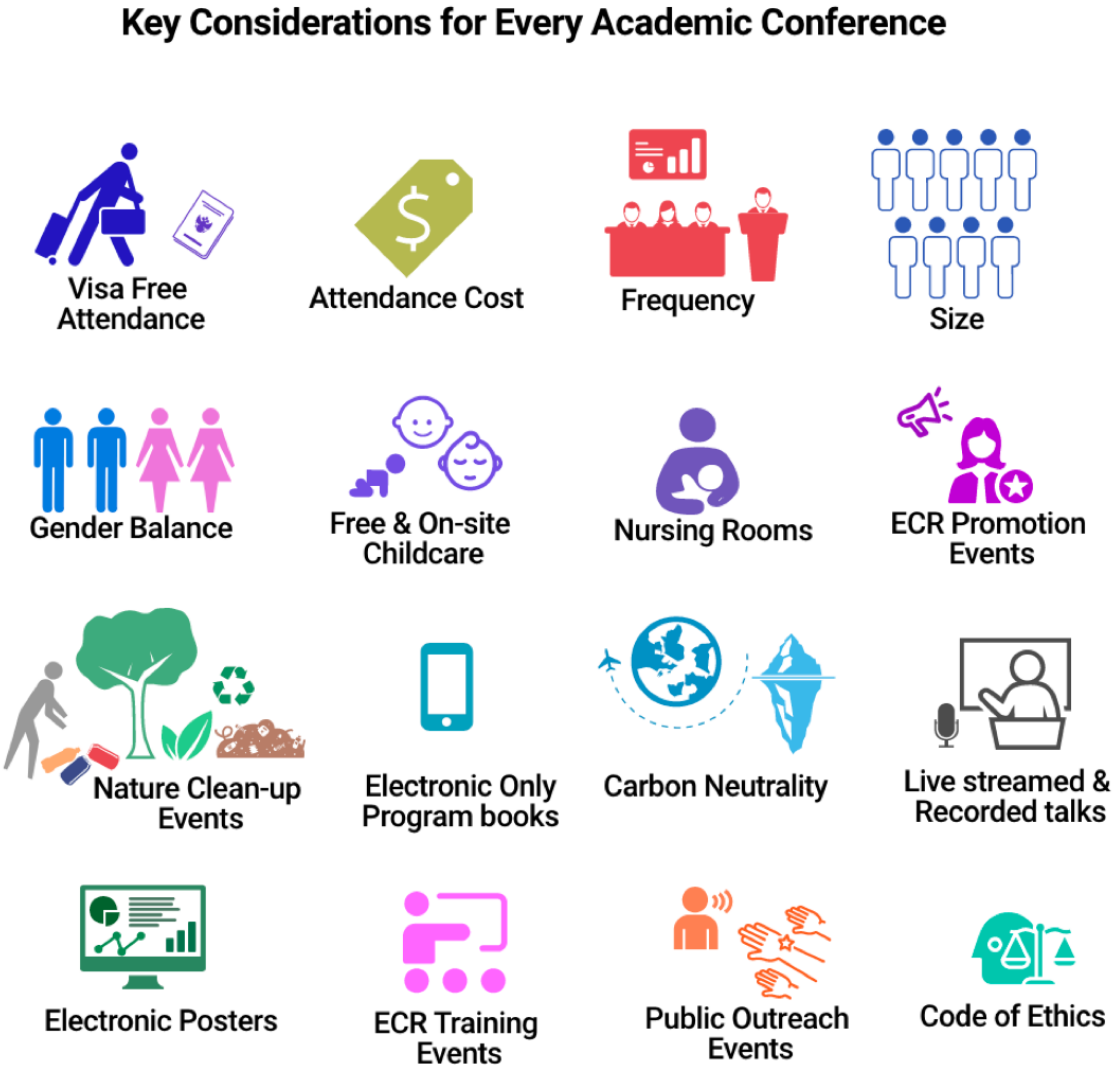

Figure 6. Key considerations for every Academic Conference. A checklist of key considerations for in-person or virtual regional conferences, virtual national, and international conferences for researchers, funders, scientific societies and conference organizers. ECR: Early career Researcher.

Conclusions

Science is a global endeavour and we as scientists have the responsibility to make conferences more affordable, environmentally sustainable, and accessible to researchers constrained by geographical location, economics, personal circumstances or visa restrictions. In an increasingly interconnected world facilitated by technological advancements in communication, alternatives have been explored to replace the in-person experience that is unattainable for many researchers, in particular early career researchers, and environmentally unsustainable for our planet. Technological advances provide the unique and timely opportunity to reform scientific conferences. Video- and virtual-conferencing of talks and poster presentations can dramatically enhance conference accessibility and improve the experience for all. Widespread digitization of conferences will increase global accessibility to knowledge during and after conferences, by increasing the diversity of speakers who are restricted in travel due to personal or political reasons and will also enable greater democratisation of science – equalising for differences between researchers of lower funding

and prominence. Digital conferences will further substantially reduce the environmental impact of these meetings as they achieve carbon neutrality. By reducing our conference related carbon footprint, our scientific communities can contribute meaningfully to the global goal of reducing greenhouse gas emissions. The prevalence and continuity of the issues associated with scientific meetings in their current form calls for all researchers, their institutions, the scientific societies, and funders to take initiative to recognize the problems, demand change, and actively participate in reorganizing national and international scientific conferences. One can imagine the new reality where streamed and recorded conference talks will become a new integral component of the global knowledge economy. Broader access to the latest scientific developments will further accelerate knowledge gain and sharing of ideas and innovation everywhere, leading to better use of researchers' time and funds. This future will be more beneficial for science and the broader public. It will be necessary to radically reassess the exact purpose of scientific meetings and to recraft the conference format for widespread digital access so that diverse researchers can attend and build the relationships that are essential for success in science. Science aspires to contribute to the solutions of humanity's greatest challenges and hence we should responsibly lead by example to create more open, inclusive and kinder research environments as we advance knowledge.

Conflicts of Interest

The authors declare no competing financial interests. The authors are all members of the *eLife* Community Ambassadors program to promote responsible behaviors in research and research culture. SS and BS are members of the *eLife* Early Career Advisory Group.

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