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ESSAY

The elephant in the conference room: reducing the carbon footprint of aquatic science meetings

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Scientific Significance Statement

The unsustainability of conferences, whose carbon footprint is mostly made of air travel, has remained an academic taboo, even more so that virtual conferences, despite being carbon-efficient, have revealed their limitations. This concern bears an even greater significance for the Association for the Sciences of Limnology and Oceanography (ASLO), considering its emphasis on climate change-related issues. This essay seeks to raise awareness and stimulate action within the ASLO community, building upon well-established scientific approaches. We perform an estimation of the travel-related CO_2 emissions of the aquatic science meetings (2004–2023), further used as a benchmark to explore alternatives to significantly reduce emissions while retaining physical attendance. Taking the leap toward such alternatives would make ASLO a role model of a genuinely sustainable and committed scientific society.

The ASLO community is firmly committed to a sustainable future, and themes of the past conferences often infer a link between aquatic systems evolution and climate change. At the latest Aquatic Sciences Meeting (ASM) in 2023, climate change and carbon-centered topics were salient themes, making up to 50% of all contributions (Fig. 1). Many keynotes were remarked on for their willingness to engage toward actions and solutions and go beyond the sole report of dangers and threats posed by climate change and other overpassed planetary limits.

Taking part in international scientific conferences such as ASM makes an integrated component of our academic life. Expectations from scientific conferences are to provide an opportunity to stay informed about the latest developments, disseminate one's own research, discuss perspectives and ideas, and get inspired. Scientific conferences also foster a sense of belonging to a community and offer a social context in which to expand research networks. In line with this, academic incentives and travel support are high and on the rise (Bojica et al. 2022). Yet, scientific conferencing also generates significant CO_2 emissions at the Worldwide scale. Eighty percent of the carbon footprint of international conferences is made up of air travel, with a lower estimate of roughly 1 tCO_{2-e} (metric tons of carbon dioxide equivalent, that is,

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Data Availability Statement: Data and codes can be found at https://github.com/mepLAKES/ASLO_C_footprint.

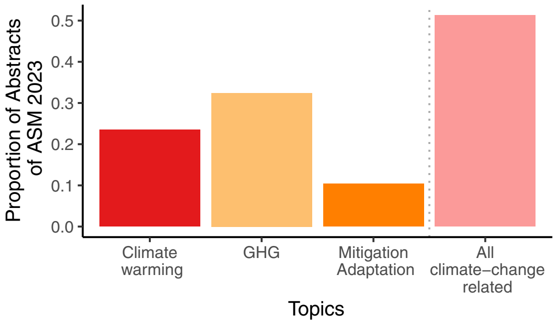

Fig. 1. The proportion of the 2029 abstracts presented at ASM 2023 containing terms related to climate warming (i.e., at least one occurrence of "warming," "climate change," "warmer"), to greenhouse gases (GHG, i.e., at least one occurrence of "carbon," "greenhouse gas-es," "CO_2," "methane," "emissions," "GHG") and to mitigation and adaption (i.e., at least one occurrence of "storage," "mitigating," "mitigation," "blue carbon," "carbon capture," "adaptation"), and the total proportion of climate change related terms (i.e., at least one occurrence of any of the terms above). Estimates are extracted from a text-mining analysis from the full abstract booklet (*see* Data availability statement).

the number of metric tons of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas) emitted per attendee for transportation (Klower et al. 2020; Tao et al. 2021). If half of the 8 million worldwide academics were to take part annually in an international conference (Sarabipour et al. 2021), transporting academics to international conferences would generate a back-of-the-envelope estimate of 4 $MtCO_{2-e}$, rivaling with annual emissions of countries such as Niger, Nicaragua, or Latvia (Crippa et al. 2022).

Meeting the Paris Agreement to contain warming to the 1.5°C target requires that the emissions per capita fall down to 2.3 tCO_{2-e} by 2030 (Gore 2021), while, due to their hypermobile lifestyle, the sole professional travel-related annual emissions for academics can easily reach 6 tCO_{2-e} per capita (Ciers et al. 2019). The significance of the carbon footprint of scientific conferences has led individual academics and scientific societies to question the current model for conferencing (Malcolm 2008; Achten et al. 2013; Arsenault et al. 2019; Klower et al. 2020; Tao et al. 2021). Despite extending beyond our immediate community, this issue holds particular significance for us within the ASLO community, as we travel the World and generate such greenhouse emissions specifically to meet and devise climate-related matters and the resilience of aquatic systems.

It is not the 1st time that the carbon footprint of ASLO conferences has been raised (Harazin 2020). However, we are unaware of any previous attempt to quantify the carbon footprint of ASM, although the exercise has already been undertaken for closely related scientific communities, such as the Ecological Society of America (Alexandra and Jarrett 2011) or the American Geophysical Union (Klower et al. 2020). We believe that this sizing exercise is important for two reasons. First, experience shows that even scholars working in scientific fields closely related to the issues of climate change tend to underestimate their own travel-related emissions (Whitmarsh et al. 2020; Passalacqua 2021). Second, quantifying the C-footprint of ASLO conferences is a required benchmark from which we can explore the efficiency of scenarios aimed at significantly reducing the carbon footprint of ASM while preserving its essence.

Many ways are being evoked to engage in a more sustainable conferencing model (moving online or hybrid, optimizing location, setting meatless conditions; Leochico et al. 2021), in which actual efficiency in reducing emissions is rarely quantitatively assessed. Going 100% online appeared, at 1st sight, as the most straightforward way to run conferences for <5% CO_{2-e} emissions of traditional conferences (Klower et al. 2020; Tao et al. 2021). However, our past 3-yr virtual experience has shown that it largely undermines several of the benefits we expect from conferencing and face-to-face interactions (Brucks and Levav 2022). Is there then a way-out, by which we could significantly reduce the carbon footprint of conferences while escaping the ghost of going fully online?

Travel-related CO_2 emissions of ASM

We estimated the travel-related CO_{2-e} emissions of ASM from 2004 to 2023, from a computational approach similar to Klower et al.'s (2020) study. Based on anonymized attendees' data for each ASM, we computed the distances between the attendees' closest airport and the main airport of the conference venues. For a 1st assessment, we assumed that all attendees flew to the conference location and used a conservative estimate (only direct flights in economy class). Computed emissions (CO_{2-e}) included greenhouse gases produced by fuel consumption, emissions associated with extracting, refining, and transporting fuels, and changes in radiative forcing due to water vapor emissions at higher altitudes (average emission factor of 163 $gCO_{2-e}\ km^{-1}$). In a 2nd step, we considered that attendees within 1000 km of the conference venue used landbound-based transportation (i.e., rail, coach, or shared car, considering an average emission factor of 30 $gCO_{2-e}\ km^{-1}$). All conversion factors were extracted from the greenhouse gas reporting of United Kingdom (Department for Energy Security and Net Zero and Department for Business 2022). We also assessed the CO_{2-e} emissions saved by the ASM 2023 initiative of meatless catering, considering that a meat-based and a vegetarian meal corresponds respectively to 3.07 and 0.68 $kgCO_{2-e}$ per capita (Takacs et al. 2022). For methodological details and reproducibility of the essay, we refer to our GitHub (*see* Data availability statement).

Total CO_{2-e} emissions for a 1-week ASLO conference ranged between 0.5 and 4.5 $ktCO_{2-e}$ over the past 20 yr, with an average value of 2.1 $ktCO_{2-e}$ (Fig. 2a). 56% of travel-related emissions were due to long-haul flights (>4000 km one way). The interannual variability of total emissions results from both the conference's location (Fig. 2b) and the attendance (Fig. 2c). Mean emissions per attendee were 1.3 tCO_{2-e}, a

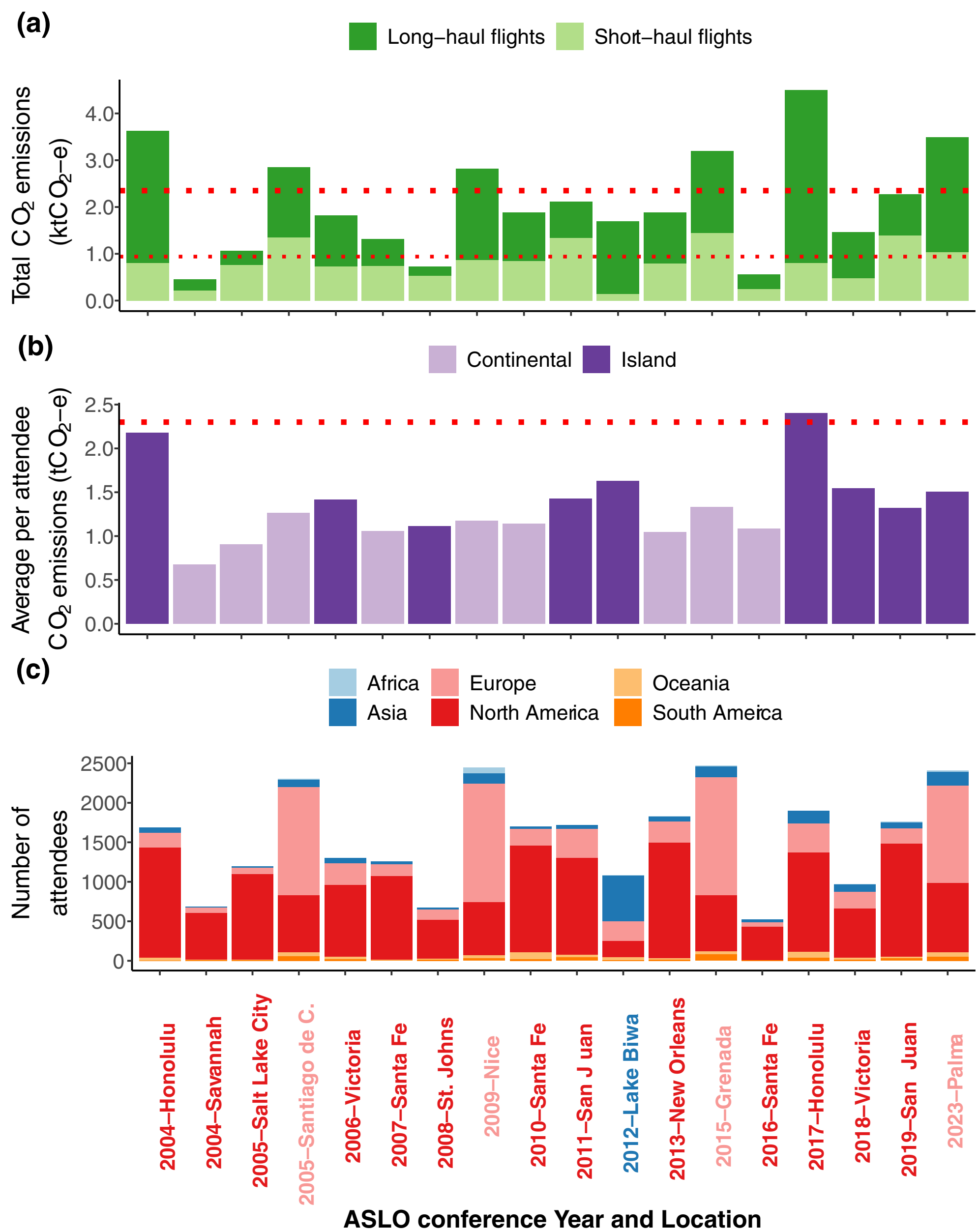

Fig. 2. Emissions and attendance for the ASLO meetings in 2004–2023. (**a**) Travel-related total CO_{2-e} emissions associated with short- and long-haul flights (limit = 4000 km one way), the thin and thick dotted line represent the annual CO_{2-e} emissions for, respectively, 200 and 500 people (worldwide average in 2023). (**b**) CO_{2-e} emissions per attendee as a function of continental or island location of the venue. The dotted line represents the target annual emissions per capita by 2030 to match the 1.5°C Paris Agreement (**c**) total number of attendees and distribution per region. Color codes of conference sites (*x*-axis) and bars are the same.

number that is comparable with what had been estimated for international conferences of other scientific societies (Klower et al. 2020), but varied considerably depending on the venue. Islander venues generated a 53% increase of the emissions per attendee, with record emissions from conferences held in Honolulu. Finally, the delocalization of the conferences outside North America since 2006 has fulfilled the goal of ASLO to diversify the origin of attendees and increase attendance (Fig. 2c). ASM held in Europe were, on average, twice more attended than those in Northern America, and attendees from Europe or Asia preferentially attended ASM held on their own continents.

Marginal fixes

As Hawaii meetings stand out in promoting the highest emission both per conference and per attendee, excluding outskirt, islander locations is an essential lever to cut-off travel-related C-emissions for ASM (Harazin 2020). However, mainland, central, well-connected locations still lead to per-capita emissions above 1 tCO_{2-e}; that is, 46% of what we should emit within a full year by 2030. Rendering ASM sustainable will not be acquired by acting on conference location alone.

Seen as an immediate lever to reduce the carbon footprint of academics, more and more universities from the North are encouraging attendees to buy carbon credits. However, we argue that relying on the purchase of carbon offsets to compensate for emissions generated by scientific conferencing cannot be considered an efficient or acceptable alternative. Carbon offset projects backed by airlines fail to remove any carbon dioxide (Greenfield 2021) and rely on overstated promises of true carbon removal (West et al. 2020). On the carbon market, 88% of the sold offsets do not constitute any emission reduction (Probst et al. 2023), and more than 90% of rainforest carbon offsets by the biggest certifier are worthless (West et al. 2023), to the point that the so-called carbon offset projects could even worsen climate change. Besides being counter-effective, carbon credit is a very lucrative trade that favors those who could afford to purchase such offsets while counteracting ASLO's efforts to get more inclusive.

Exploring structural alternatives for cutting down emissions

Shifting to multi-hub conferences is the structural change that we explore here. The principle of multi-hub conferences implies that meetings take place in several locations at the same time. Attendees go to their closest hub (Klower et al. 2020; Parncutt et al. 2021). Face-to-face interactions are maintained within hubs, while hubs are connected by virtual links (Parncutt et al. 2021). Using the data for ASM 2023, whereby attendance and attendees' diversity were high, we assessed the net reduction of travel-related CO_{2-e} emissions of

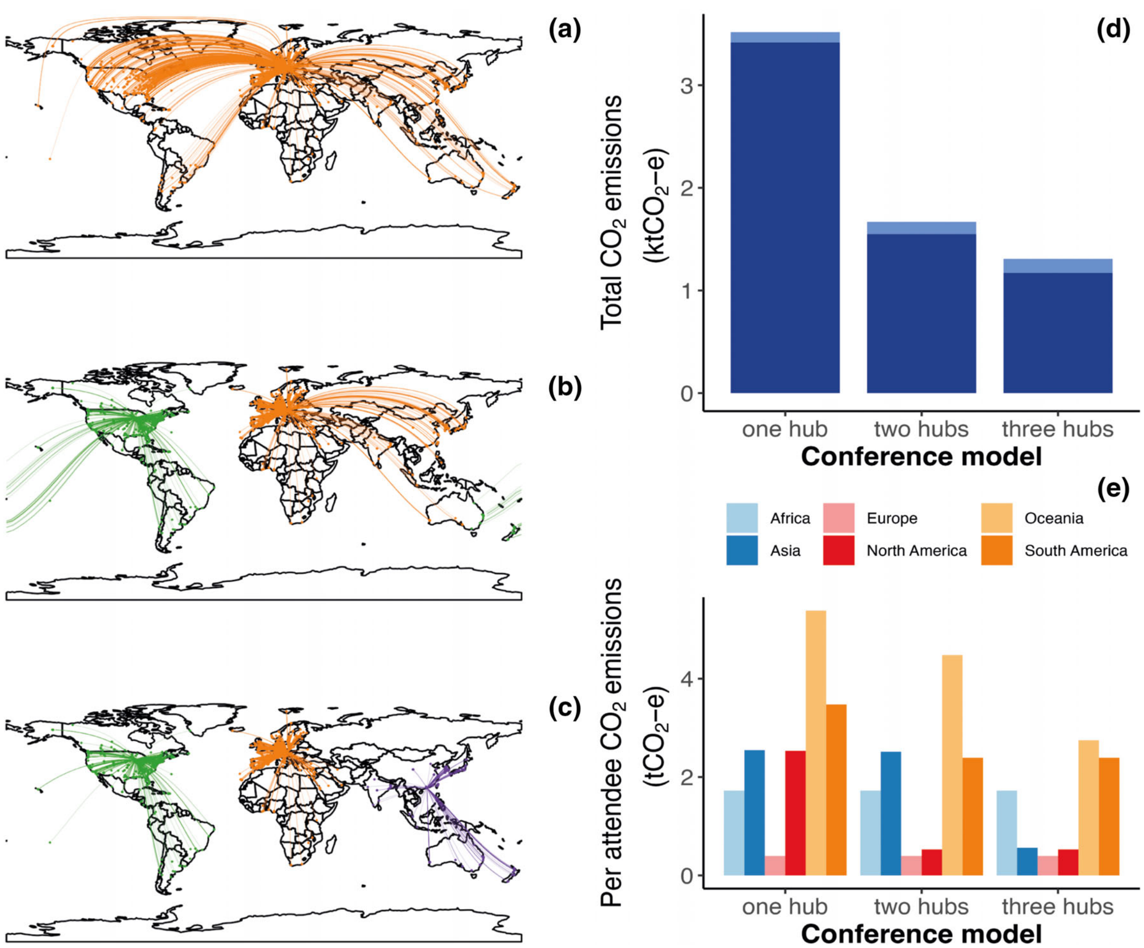

Fig. 3. Travel-related emissions as a function of conference model. Flights maps (**a**) within the traditional ASM model (one hub in Vienna), (**b**) for a two-hub model (Vienna and Madison), and (**c**) in a three-hub model (Vienna, Madison, and Hong-Kong). (**d**) Total CO_{2-e} emissions as a function of the conference model. The light blue area presents emissions saved by switching to land-bound transportation for attendees traveling <1000 km one way (**e**) averaged CO_{2-e} emissions per capita as a function of attendees' continent of origin in the different conference models.

shifting from the traditional to a multi-hub model for ASM (Fig. 3).

We compared flight paths and CO_{2-e} emissions between the current traditional ASM model and scenarios of a two-hub model (one central location in Europe and one in North America) and a three-hub model (adding a central hub in Asia). Adding continental hubs significantly reduces the number of intercontinental flights (Fig. 3a–c). The sum of traveled distances decreases significantly as the number of hubs increases, from 22 million km flown in the traditional one-hub model down to 10 million km in the two-hub and 8 million km in the three-hub scenario, leading to a reduction of total CO_{2-e} emissions by 52% and 65%, respectively (Fig. 3d). Multi-hubs contribute to reducing per-attendee emissions, with a more balanced share of the C-burden across the attendees' continent of origin (Fig. 3e).

Promoting land-bound transportation has a rather minor impact on CO_{2-e} in a one-hub model (<3% of total CO_{2-e}). But with the multi-hub model, the potential benefit of promoting land-bound transportation is >10% (Fig. 3d). Serving vegetarian food has only a symbolic impact compared to travel-related emissions in a one-hub scenario. The "meatless day" at the ASM 2023 saved 11 tCO_{2-e}, that is, 0.3% of the total emissions of the ASM 2023. In a three-hub scenario, shifting to a meatless week (−58 tCO_{2-e}) has the potential to decrease emissions by another 5%.

Ways forward

The IPCC is clear that limiting warming at manageable levels requires that all sectors do their share, and scientific societies make no exception. In the current academic model, we are stuck within a cognitive conundrum (Whitmarsh et al. 2020): we travel the world to present our studies on the inner causes and consequences of climate change, leading to a demonstrated undermining of our scientific credibility (Attari et al. 2016), while being part of a scientific society committed to raising public awareness on water-related environmental challenges (www.aslo.org). And yet, tackling the question of the C-footprint of conferences, and of academic activities in general, remains an uncomfortable and sensitive topic, if not a complete taboo (Higham and Font 2020; Whitmarsh et al. 2020).

The traditional conferencing model is "an outdated luxury the planet cannot afford anymore" (Malcolm 2008). As shown here, low-carbon ASM will require more than a marginal fix, whereby we just avoid outskirt locations or promote carbon offsets. Here, we argue that only structural changes can lead to more sustainable conferencing. Switching to multi-hub ASLO conferences would significantly cut-off on the travel-related CO_{2-e} emissions while maintaining efficient face-to-face scientific interactions. As multi-hub conferences develop, favoring landbound transport and serving vegetarian food also make an impactful difference, while being symbolic only in a one-hub scenario. While here we aimed only for a 1^{st}-order demonstration of the potential of multi-hubbing, the implementation of such a model shift should come with a revision of what drives the choice of the venues, echoing concerns of Harazin (2020). The choice of the hub locations should be based on criteria oriented toward reducing the C-footprint, and more generally the environmental impact, over touristic attractiveness. For instance, an isochrone map could define optimal cities reachable by train within 10 h, thus incentivizing economic returns for cities and countries actively investing in railway transportation.

Some may argue that multi-hub conferences will be challenging to organize, due to time zone differences, and difficulties in managing both online and physical communication. If indeed this would imply to revise our habits, other societies, some of size comparable to the ASLO, have already undertaken the turn (such as the American Meteorological Society in 2022 and the Royal Geographical Society in 2023), and have provided guidelines and feedbacks (Parncutt et al. 2021; Kremser et al. 2024). Those technical requirements should be an integral part of the ASLO's contract specification with conference organizing companies, many of which are currently developing capacities for multi-hubbing.

Others may express concerns regarding the financial implications of adopting a multi-hub model because of the escalated demand for audio–visual equipment across diverse venues. Nonetheless, technological advancements have led to more affordable, compact, and reliable audio-visual gear. Additionally, hosting conferences in smaller hubs could potentially necessitate more modest and cheaper conference venues than those needed for the typical one-hub model. While it remains challenging to precisely gauge the financial impact of multi-hubbing at this stage, it is imperative to couple the multi-hub framework with a financial restructuring to ensure that registration fees do not increase.

Engaging in a transformative turn to truly more sustainable conferences through multi-hubs has also the potential to leverage some of the well-known inequalities of traditional conferences, a central mission of the ASLO community. Conference travel opportunities are strongly inequitable (Sarabipour et al. 2021). For economic, family or time-related reasons, academics working in the developing world, and those with care responsibilities have reduced access to the privilege of conference travel, with potential disadvantages to their career development. This also appears in the presented data as scholars outside North America favor ASM within their (sub)continents, when it does not imply traveling too far. Multi-hub ASM will serve ASLO's commitment to diversity, inclusion, and equality, by reducing the cost, time and C-burden associated with ASLO conferencing. The average traveling distance per attendee is cut to less than a 3^{rd} in the three-hub model (1300 km) as compared to the traditional one-hub model (4600 km). Thereby, shall this multi-hub model be successful and lead to a rebound effect of +25% of attendance, most of the additional attendees could travel with landbound transportation, leading to a relatively low increase in CO_2 emissions. Finally, our scientific credibility is challenged by our current difficulty to "walk our talk" (Attari et al. 2016) and actively engaging into a transformative model specifically targeted to reduce the C-emissions of conferences is one lever to restore public trust.

Some scholars have already chosen not to attend conferences overseas (Higham and Font 2020), even at the risk of being less visible. Yet, a real transformative change implies a collective engagement and a cultural change (Whitmarsh et al. 2020), only possible if led and fostered by scientific societies. Rethinking the conference model provides an opportunity to revise what makes the success of a conference. How often do we need to attend? Is a bigger conference more effective in terms of scientific outcomes and feedbacks? Boosting symbolic capital and enjoying paid trips to nice locations are also reasons that drive frequent conference participation. How much of our perceived incentive to attend is actually a social construction rather than a real scientific benefit? ASLO has already proven its commitment to diversity and equality issues, by putting it into action through its "amplifying Voices" program. For such a strong community of academics at the forefront of climate issues, taking the leap toward committed actions for a sustainable and climate-friendly conference model would place the ASLO at the vanguard of scientific societies.

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