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published in
2022 International Conference on ICT for Sustainability (ICT4S)
2022

DOI (link to publisher)
10.1109/ICT4S55073.2022.00027

document version
Peer reviewed version

Let's Start Reducing the Carbon Footprint of Academic Conferences

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***Abstract*—The COVID-19 pandemic forced researchers to move academic conferences to a virtual format; but also brought attention back to the carbon footprint of their physical format. In general, while conferences can follow different formats with a different carbon footprint, the related factors of influence remain unclear, hence hindering informed decisions on how to organize and attend them.**

This work provides a preliminary study of the carbon footprint of academic conferences and the trade-offs between alternative conference types. First, we conducted a systematic literature review (SLR) to identify factors that contribute to the carbon footprint of on-site, virtual, and hybrid conferences. Second, we conducted an interview survey among steering committee members of a pilot of prominent international conferences to complement the SLR.

There is agreement in the literature and the research community that on-site conferences suffer from travel-related emissions among many other factors. While the on-site type benefits from strong networking possibilities, the virtual and hybrid types can reduce carbon emissions significantly. Notwithstanding, we miss a generic framework that accounts for all revealed carbon footprint factors in each conference type. Also, compared to carbon *offsetting*, carbon *handprinting* as a footprint reduction option is considered in neither the literature nor the research community. Among the results, we provide a first sustainability model to compare current and future conference types according to their sustainability trade-offs. The model can be used as a decision-making tool by, *e.g.,* conference organizers.

***Index Terms*—Carbon Footprint, Conferences, Sustainability, Systematic Literature Review, Interview Survey.**

I. Introduction

As the recent global COVID-19 pandemic has forced everyone to rethink their travel habits, researchers have simultaneously identified a related worldwide decline in CO_2 emissions. While academic work continues, scientific conferences are being held virtually, hence making travel superfluous. This made researchers question with new energy, the contribution of international conferences to global warming. The present work wants to add to this discussion by providing a review of the carbon footprint of scientific conferences and a first analysis of the related trade-offs.

The aim of this work is twofold. We first conduct a systematic literature review (SLR) to identify the major CO_2-containing factors, such as traveling and food planning, that count toward the carbon footprint of scientific conferences. By identifying such factors, the footprint can be calculated and compared among conferences that follow either the (i) traditional on-site approach, (ii) virtual approach, or (iii) hybrid approach. Second, we carry out a survey among a pilot of international and prominent conferences. This survey complements the SLR by providing insights from experienced conference organizers about scientific conferences and associated CO_2-containing factors. These two studies, the SLR complemented by the survey, give a first overview of emissions related to different conference types. The results can be used to raise awareness of personal impacts on climate change among researchers.

The main contributions of this paper are:

- a reference list of state of the art carbon footprint **factors** related to the three alternative conference types;
- a first comparison of these three conference types according to their **carbon footprint**;
- a first comparison of these three conference types according to their **sustainability model**;
- **suggestions** for conference organizers on how future conferences can be planned and executed to achieve sustainability;
- a first discussion about current **research challenges** related to this topic.

The rest of the paper is structured as follows. After presenting some background (Section II) and discussing related works (Section III), we describe the design and execution of our study (Section IV). The results are outlined in Section V and discussed in Section VI. We close with the threats to the study validity (Section VII) and conclusions (Section VIII).

II. Background

As mentioned, the global pandemic COVID-19 led to a worldwide decline in greenhouse gas (GHG) emissions; *e.g.,* for 2020 it was accounted for about 6% [29]. However, it is still necessary to reduce more annual GHG emissions in order to reach the goal of limiting the global warming to 1.5°C. In this study we use the **carbon footprint** which describes the total GHG emissions related to one individual or product, measured in tons of carbon dioxide equivalents ($t\ CO_2\text{-}eq$) [25]. To describe the carbon footprint of academic conferences we use activities, services, or actions which generate $CO_2\text{-}eq$.

If carbon emissions are inevitable, **carbon offsetting** is a common tool for climate protection and compensating GHG emissions [14]. A common approach is to donate to organizations which invest in emission mitigation, for example, to plant new trees. However, carbon offsetting has also experienced critique, since doubts regarding these mitigations have been expressed; organizations and their associated projects can give the false impression that emissions are fully compensated and therefore no harm is done [13].

Contrary to the carbon footprint, we are interested in the **carbon handprint**. While the footprint describes the negative aspects of certain actions on the environment, its main goal is to minimize someone's/something's footprint, or bring it close to zero [12]. The term *carbon handprint*, instead, engages in the discovery of positive possibilities of *healing* the environment to a certain degree. In this research the term is used according to the definition of Grönman et al. [12]:

> "A handprint refers to the beneficial environmental impacts that organizations can achieve and communicate by providing products that reduce the footprints of customers. A carbon handprint is the reduction of the carbon footprint of a customer or customers."

As **conference types** we distinguish between three different types: i) on-site, ii) virtual, or iii) hybrid. Type (i) conferences are held entirely physical, at a specific location, city, and country. All participants have to go to the conference's venue to attend. Type (ii) conferences are held fully virtual via video or virtual meetings. All participants and members attend remotely. Type (iii) identifies a combination of type (i) and (ii). Participants are assigned to one or multiple *hubs* whereby these hubs are remotely connected to other hubs in other regions or continents.

Beyond the carbon footprint, *i.e.,* the environmental impact of conferences we are interested in the trade-offs between the different conference types. To discuss and classify these trade-offs in a structured manner, the four **sustainability dimensions** according to Lago et al. [20] are considered: (i) technical, (ii) economic, (iii) social, and (iv) environmental.

III. Related Work

In the context of computer science, Vardi [30] describes the evolution of computing-research conferences and declares the system as outdated. The review process of publications as well as the traditional, physical on-site conference approach should be reconsidered from scratch. Next to problems with the review process of traditional conferences, the author claims that on-site conferences should not be just replaced by virtual conferences while keeping the same structure: "spending a day in virtual space is quite difficult and screen fatigue is a real phenomenon". The aspect of carbon emission is discussed only marginally and is used as an argument among others to embark on the debate about changing the computing-research publication system.

There exist many studies that conduct a systematic review about the carbon footprint, however, their focus is on contexts such as the textile industry [33], supply chains [11], or fashion operations [18]. Academic conferences are neglected.

In the context of computer science conferences, Hicks et al. [15] identifies the need of reducing conference related carbon emissions. The preliminary report examines necessary changes as the switch from on-site conferences to virtual conferences taking the climate change into account. The authors emphasize the "personal lifetime carbon budget" of a scientist and to what fraction this budget would be used by attending an on-site conference. Due to the focus on air travel and the switch to video conferences, the report neglected other factors. Overall, we can observe the need of a comprehensive literature study about the carbon footprint in the context of academic conference. A detailed taxonomy with categorization about relevant carbon footprint factors was not observed in the reviewed literature together with the distinction of different conference types.

IV. Study Design and Execution

This Section first describes the overarching study goal, the research questions and the study replicability (c.f. Section IV-A). For conducting the present research a mixed method approach is used; accordingly, our results are based on a systematic literature review followed by an interview survey among committee members of a pilot of prominent conferences. Figure 1 depicts the overall study design. The *SLR* is explained in detail in Section IV-B, while the *interview survey* is explained in Section IV-C. The outcomes of the *joint synthesis*, *i.e.,* the results, are examined in Section V.

To ensure the replicability and quality of our work, an online replication package [3] provides all intermediate and final results as well as documents to replicate the research, *e.g.,* the review spreadsheet recording the SLR process. Threats to validity and related mitigations are discussed in Section VII.

A. Goal and Research Questions

The goal of this study is to answer the main question *"What is the carbon footprint of scientific conferences?"*. This main question was refined into three more concrete sub-questions shaping the present research:

- RQ1: *What are the existing factors to describe the carbon footprint of scientific conferences?* By answering this research question, we aim to identify and describe factors that are related to the carbon footprint of academic conferences. By grouping the factors along the conference type, all three types can be evaluated against each other. Uncovering previously unassessed factors could raise awareness among conference organizers and participants.
- RQ2: *Which factor is the most/least influential, and to what extent is this factor responsible for the overall carbon footprint of conferences?* Given the factors identified in RQ1, the purpose of RQ2 is to uncover the most CO_2-containing factor alongside the least CO_2-containing factor. By answering this question, we can derive actual actions to reduce the carbon footprint of a certain conference.
- RQ3: *What are existing factors of scientific conferences that increase a researcher's personal carbon handprint?* By focusing on the carbon footprint of one individual, factors are taken into account which are responsible for increasing the worldwide CO_2 emissions and

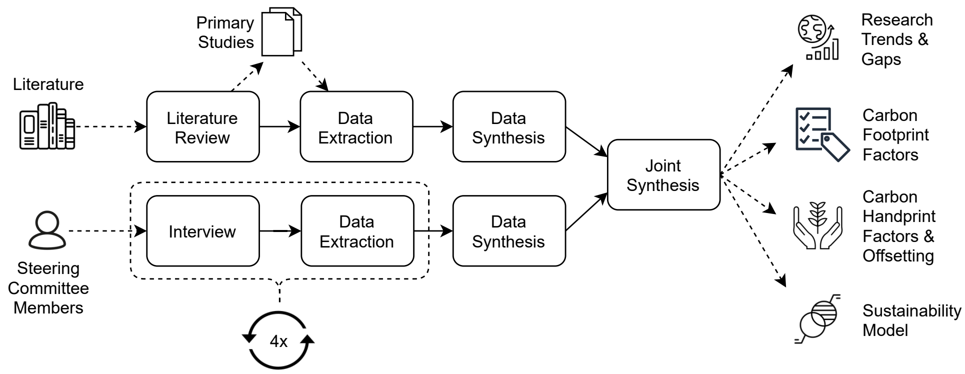


Fig. 1: Study design overview

damage of our environment. In RQ3, in turn, we want to examine the personal carbon handprint[1].

B. Literature Review Design & Data Extraction

The SLR was carried out by following the approach of Kitchenham [19] for designing SLRs and the guideline of Xiao and Watson [32] for conducting SLRs. This section presents all steps for the identification of the primary studies and the data extraction. The SLR is illustrated by the *literature part* in Figure 1.

1) Initial search: The search was driven by two phases: the screening phase and the actual search phase. In the screening phase several search queries were executed on different research databases to decide upon which libraries to use and to derive the search query. We tested various databases including IEEE Xplore and ACM Digital Library, the supervised search engine ScienceDirect, and the unsupervised meta search engine Google Scholar. The initial test query `CARBON FOOTPRINT x CONFERENCES x COMPUTER SCIENCE` yielded a very broad variety of results on all libraries. The studies mostly related to the carbon footprint itself without any context to conferences. Since our research questions do specifically focus on the carbon handprint and offsetting of carbon emissions related to academic conferences, we decided to develop two supplementary search queries. To limit the search results to a feasible number of studies, the search terms were restricted to the TITLE field. The exact search queries including the used synonyms are shown in Table I.

The final search queries were performed on the scientific meta search engine *Google Scholar*. The digital library was considered for the following reasons: (i) research has shown that Google Scholar has the highest intersection when it is compared to Web of Science and Scopus [22], (ii) the search engine provided the largest number of potentially relevant studies compared to the previously tested databases (IEEE Xplore, ACM Digital Library, ScienceDirect), (iii) the queries can also be run through third-party tools and extracted automatically, which is described in detail below.

[1]Carbon handprinting should not to be confused with carbon offsetting; since handprint is a novel term [12], this research also investigates and discusses carbon offsetting related to academic conferences.

Q#1	`TITLE_WORDS:(conferences AND (carbon OR footprint OR emissions OR co2))`
Q#2	`TITLE_WORDS:(conferences) AND KEYWORDS:(\carbon handprint" OR \carbon budget" OR handprint OR offsets)`

TABLE I: Executed search queries on Google Scholar

We used *Publish or Perish*[2] as a software tool to execute both search queries and retrieve Google Scholar results. The result lists were exported as BibTeX. To keep track of the publications during the entire research, we used Zotero[3] as a publication library management tool. Zotero supports the process of retrieving meta information about all publications at once as batch job and retrieving the files (PDFs) corresponding to the citations. Results were excluded if they were either not accessible or the title uncovered a not relevant study. For further processing, the results from *Q#1* and *Q#2* were merged, cleared of duplicates, and erroneous metadata cleaned up.

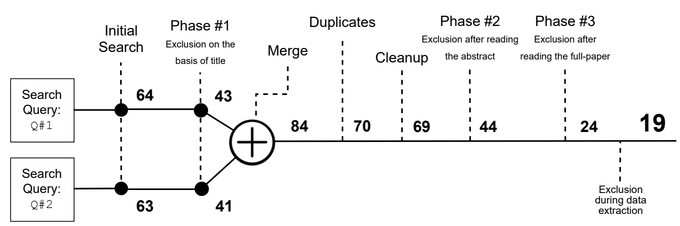


Fig. 2: Overview of the study design, the different study stages, and the number of publications

2) Application of selection criteria: Following Kitchenham [19], publications were selected based on pre-defined inclusion and exclusion criteria in Phase #2 (described below together with their rationale). As summarized in Figure 2, the whole process resulted in a final set of **19** primary studies.

IC1: *The study is mainly about the carbon-[footprint, handprint, offsetting] in relation to academic conferences.* We were interested in discussions about the carbon-

[2]Publish or Perish (v7) - https://harzing.com/resources/publish-or-perish
[3]Zotero (v5) - https://www.zotero.org

[footprint, handprint, offsetting] in the context of academic conferences. For instance, studies that discuss the impact of traveling on global warming by attending scientific conferences.

IC2: *One of the main objectives of the study is to present one or multiple factors to describe the carbon-[footprint, handprint, offsetting] of academic conferences.* If one of the objectives of a study is to identify or discuss a certain factor related to academic conferences, it was relevant to our review. *E.g.,* a discussion about the factor food in the context of conferences.

IC3: *The study is provided in the form of a scientific article.* Only peer-reviewed articles were selected. Internet blogs, books, or slides were excluded.

EC1: *The study discusses the carbon-[footprint, handprint, offsetting] not in the context of academic conferences.* We were not interested in papers that examine, for instance, the carbon footprint of a certain manufacturing process.

EC2: *The relation between the carbon-[footprint, handprint, offsetting] and academic conferences is only discussed marginally.* We were interested in papers, whose primary focus it is to examine the carbon-[footprint, handprint, offsetting] of conferences. If our primary research goal is only discussed indirectly, we did not include it.

EC3: *The study is not accessible.* To create a repeatable and transparent study, the consulted paper needs to be accessible.

EC4: *The study is not written in English.* All studies which are not in English were excluded. This allows the most possible access.

3) Data Extraction: All primary studies we gathered, examine the carbon footprint related to academic conferences. To uncover gaps in the literature and answer our research questions we used grouping and classification to extract necessary data. For every primary study, we followed a strict data extraction model focused on the components illustrated in the extraction meta-model of Figure 3, which covers:

- **Conference Type:** According to the prior defined conference types, these can be {*on-site, virtual, hybrid*}.
- **Carbon Footprint Factor:** Due to the iterative review process, we started with a pre-defined subset of categories. When necessary, categories were re-defined or added. All extracted factors were classified by the following groups: {*transportation, accommodation, venue, catering, ICT infrastructure, other*}.
  E.g., Factor: {*air-travel*}→*Category:* {*transportation*}
- **Sustainability Factor:** We were interested in the trade-offs between the different conference types, therefore we used the four sustainability dimensions [20] to classify the different factors as are {*technical, economic, social, environment*}.
  E.g., Factor: {*networking*}→*Dimension:* {*social*}
- **Carbon Offsetting:** No predefined grouping was used for the compensation techniques. First, we were interested whether the paper examines offset techniques, (Boolean: {*true, false*}). If so, we extracted the technique.
- **Carbon Handprint:** *ibidem.*
- **Improvements / Suggestions:** *ibidem.*

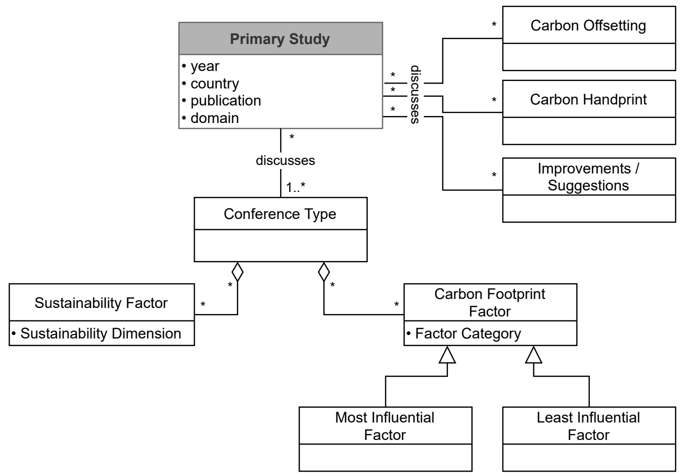


Fig. 3: Meta-model of the data extraction

4) Data Synthesis: The data obtained from the extraction phase was analyzed qualitatively. To synthesize our results we performed a "reciprocal translation" according to Kitchenham [19]. Since all primary studies are about the carbon footprint of academic conferences, additive summary can be applied. This means to "translate each case into each of the other cases" [19]. For instance, if one primary study identifies *lunch and drinks* as a relevant carbon footprint factor, and another study names *dinner*, both factors are counted towards the factor *meals and food* and the category *catering*.

C. Interview Survey Design & Data Extraction

Interviews were conducted to complement the SLR. We invited steering committee members of a pilot of prominent international computer science related conferences to share their experience and knowledge. The survey is illustrated by the *interview part* in Figure 1.

1) Interview Design: We were able to interview four steering committee members of international scientific conferences. The interviews were meant as qualitative data collection together with gaining valuable insights into conference organization processes. Therefore, the survey was designed as semi-structured interviews. The detailed structure and the corresponding questions can be found in the replication package [3]. If the interview led to other questions or guided the discussion into another direction, this was accepted and especially appreciated. Due to the COVID-19 circumstances, all interviews were conducted virtually via Zoom[4].

[4]Zoom - https://zoom.us

2) Data Extraction: The interviews were video-recorded and watched again to extract further data and extend the already taken notes. We used the same data extraction model as for the literature review (c.f. meta-model in Figure 3).

3) Data Synthesis: Like for the SLR, we used the data obtained from the interviews qualitatively. The results of the interviews are synthesized into the same table structure (c.f. replication package). This offers the possibility to observe differences and similarities between the SLR and the survey.

V. Results

The following section examines the obtained results. The SLR and the interview-survey results were technically conducted separately. For the sake of simplicity and a better overview, both results are discussed together. This will help general understanding, and uncovering the gaps between the literature and the insights from conference organizers. This part of the study is illustrated by the *joint synthesis* in Figure 1.

A. Publication Trends

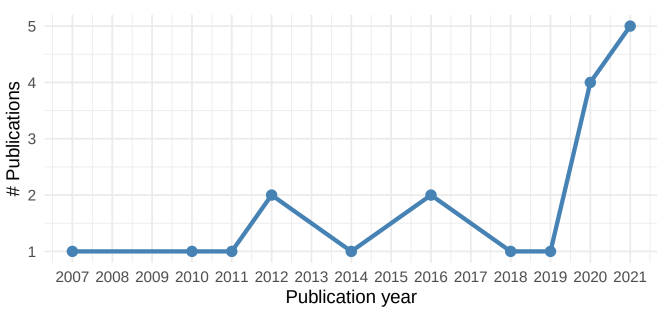


Fig. 4: Primary studies grouped by published year

By consulting the distribution of the primary studies over their publication years (c.f. Figure 4), we can see that the carbon footprint related to academic conferences has been a concern since 2007. Hamill [14] announced that if the American Meteorological Society (AMS) would commit to carbon neutrality, "the AMS would lead by example and demonstrate that we take the consequences of global warming seriously". However, the study mostly discusses techniques to create carbon neutral conferences by applying and investing in carbon offset strategies and providers. This issue will be further examined in Section V-D. Figure 4 also shows that since 2007 the scientific interest in this topic has grown to become popular over the last three years. We can identify an erratic increase between 2019 and 2020 by a factor of 4. As initially mentioned, the COVID-19 pandemic has highlighted the discussion about the carbon footprint related to travel activities. The keywords *COVID* and *pandemic* occurred in seven out of nine studies between 2020 and 2021 [4, 5, 8, 9, 16, 23, 28].

Concerning the research domain of the primary studies, Table II clearly illustrates that *medical science* dominates the number of publications with a ratio of 6:13 [4, 8, 23, 27, 28, 34]. While extracting our data we noticed that publications

Research domain	# Publications
medical science	6
transport science	2
political science	2
computer science	2
other	7

TABLE II: Number of publications per research domain

related to medical science claim that "climate change is harming human health, and needs a broad range of strategies to reduce this harm" [8]. Compared to the domain of which this research initially originated, Computer Science, only two studies [6, 26] out of 19 are discussing the topic of interest. The rest of our primary studies relates to a broad range of domains.

B. RQ1 - On existing factors describing the carbon footprint of conferences.

1) Conference Types: In the first phase, we were interested in the distribution of the different conference types mentioned in the literature in connection with the carbon footprint. The survey results are not analyzed by this section, as the moderator of the interviews ensured that each conference type was discussed equally. Hence, a comparison with the literature is not necessary nor appropriate.

Most primary studies (16 out of 19) discuss **on-site** conferences. By analyzing the publications, we unintentionally uncovered conference types beyond our definition (c.f. Section II) which are grouped into **other**, as shown in Table III: two papers discussed **hybrid** conferences; however, with a different definition. As described, we define hybrid conferences as events where attendees are assigned to one or more *hubs*, with these hubs being remotely connected to each other. Jäckle [16] defines hybrid conferences as "participants from far away join the event online, combined with the promotion of land-bound travel for those attending in person". This means that only individual attendees from far away should participate from home while attendees from the surrounding area should only use land-bound travel. Bousema et al. [4], on the other hand, leaves the choice up to the attendee, offering both a traditional on-site conference and the ability to join the event via video. The author defines our definition of hybrid conferences as **decentralised** approach.

Type	# Publications	Publications
on-site	16/19	[1, 2, 4, 5, 7, 8, 10, 14, 16, 17, 21, 23, 26, 27, 28, 34]
virtual	5/19	[2, 4, 8, 9, 28]
hybrid	4/19	[2, 4, 6, 24]
other	2/19	[4, 16]

TABLE III: Related publications per conference type

2) Carbon Footprint Factors: To answer RQ1, we extracted all carbon footprint factors and grouped them into higher-level categories. The results, *i.e.,* the reference list of state of the art carbon footprint factors are presented as a spreadsheet available in our replication package [3]. Figure 5 visualizes and summarizes this spreadsheet and the SLR results. The percentages are calculated based on the total number of publications per conference type and the corresponding carbon footprint category.

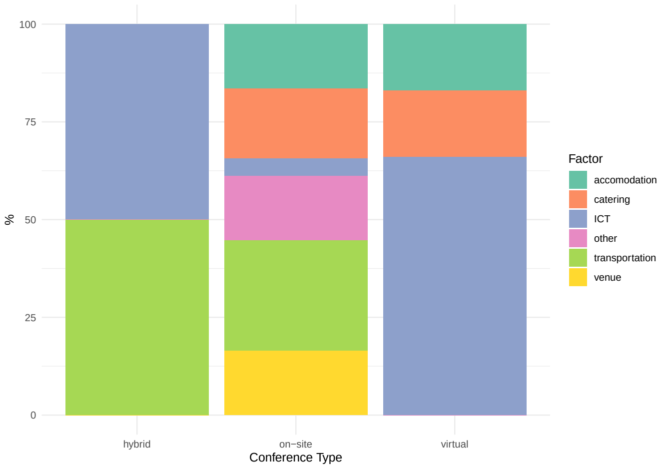


Fig. 5: Percentage of primary studies depending on conference type and carbon footprint factor

Transportation. All primary studies discuss transportation as a problem when it comes to on-site conferences. Almost all studies mention in their introduction the problem of the global warming related to our travel behaviour. Jäckle [17] shows that "a significant part of personal CO_2 emissions in developed countries results from travelling" (based on the results from Wynes and Nicholas [31]). However, traveling to on-site conferences is inherent in its nature. International academic conferences are mostly location-alternating events, where researchers from around the globe join to discuss their research in the community. It is also obvious that air travelling is the most discussed factor. A more in depth analysis of this factor is presented in Section V-C.

It is also natural that we were not able to find any factor related to transportation when it comes to fully virtual conferences as this conference type makes traveling superfluous. Only two primary studies discuss transportation as relevant factors for hybrid conferences [6, 16]. Further, Orsi [24] provides an optimization model that supports steering committee members to find the best conference location to minimize necessary travel activities by choosing the best location according to the participants origin.

Accommodation. Accommodation related factors like electricity, heating and laundry are obviously intensively discussed for on-site conferences, however, not for hybrid conferences. Someone could argue that accommodation is also necessary for hybrid conferences. Nevertheless, none of the primary studies mention accommodation as a factor for hybrid conferences, and only one interviewee mentioned accommodation as relevant. We were not able to find any paper which examines accommodation factors in detail. All publications only mention accommodation as a factor without specifying concrete impacts and measurements. *E.g.,* to calculate the footprint, Duane et al. [8] assume that "all attendees stayed at the hotel/conference venue, a $4*$ hotel, and they stayed for three nights". For virtual conferences, the authors excluded the "impact of attendees using their own residential heating and electricity resource while staying at home". Mankaa et al. [21] provide as reasoning for excluding such factors that "their impacts are quite challenging to compute".

Venue. Both, the SLR and the interview survey mention that the conference venues as relevant only for on-site conferences. However, the same argument as for accommodation holds also for the venue, *i.e.,* a venue is needed for hybrid conferences, too.

Catering. The results of this category are similar to the results of the factor accommodation. It is obvious that catering related emissions like food production and meal consumption do mostly occur by on-site conferences. The major fraction of food consumption is related to the venue and accommodation, since conference attendees consume their food mostly at the venue location or at their hotel. Allegre et al. [1] examine the carbon footprint of the gala dinner of on-site conferences.

From one interviewee, we extracted the statement "food related emissions are negligible, since food is also necessary if you work and attend a conference from home". However, this statement is a contradiction to [28]: "While people would otherwise eat at home, the environmental footprint of travel-related meals should not be ignored. Conference meals tend to be highly processed, are often meat and dairy laden, and half of catered foods frequently end up in the waste bin." We can deduce that emissions are more burdensome for on-site catering.

ICT Infrastructure. Virtual conferences naturally require an increase in ICT infrastructure related factors compared to on-site conferences. Faber [9] presents a holistic "framework to estimate emissions from virtual conferences". The author considers many different factors like "data about participant computers, Internet energy intensity, network data transfer, server power ratings" to calculate the emissions. For each considered factor, the author provides the related measurement unit, formula, and a thorough discussion of the relevance of such factors. This is also the only study we found that considers factors like the manufacturing process of devices and the related carbon footprint, *i.e.,* the participant's notebook. One could argue that the manufacturing process and carbon footprint of the ICT devices themselves are also relevant for on-site and hybrid conferences. However, such factors are not considered relevant in any of our primary studies.

Other. We identified as "other" the carbon footprint factors for which we were not able to find a suitable category. As shown, these factors were only examined for on-site conferences. Disposable items such as takeaway coffee cups, gifts for conference speakers or the traditional conference bag have a non-negligible carbon footprint and could be avoided without changing the conference type. This was also discussed by our interviewees as: "Superfluous items that would actually create waste and generate emissions in their production could simply be avoided by either not providing them anymore or by sustainable alternatives. The promotions and awards could be replaced by carbon offset offers."

Overall, we observe that the primary studies have a strong focus on on-site conferences and that transportation is discussed the most. If we compare the SLR results with the interview survey results, we observe that the SLR examine the factors more in depth. However, we also see an affirmation of the observed pattern, namely that on-site conferences have the highest carbon footprint and include most factors.

C. RQ2 - On the most/least influential factor and the related carbon footprint.

To answer RQ2, we extracted from each primary study the factor which is stated as the most influential—if presented. For **on-site** conferences, all primary studies mention either *Transportation* in general or explicitly *Air Traveling* as most influential factor. For the virtual and hybrid types, however, it is not that obvious. Both *Electricity* [8, 16] and *Network Data Transfer* [9] are mentioned as major contributors to the carbon footprint of **virtual** conferences. When it comes to **hybrid** conferences, only *Transportation* is considered by [6, 16, 24] as the most influential factor.

Since both on-site and hybrid conferences suffer from transportation and air traveling, we want to examine this factor more in depth. The statement by Pierce et al. [26], *i.e.,* "[Air-travel] emissions have no near-term technological fix, as jet fuel is difficult to replace with renewable energy sources", is in line with one interviewee as they claimed "there exists no trade-off between flying and positive aspects of on-site conferences. We have to ask ourselves: can we afford the on-site conference type also in the future? Without finding a solution with renewable energy, the answer is—no. We have to create constraints for on-site conferences by cutting off flying and long-distance trips if the energy consumption per person cannot be reduced in the future."

We were also interested in the *actual* footprint and CO_2 emissions of academic conferences, measured in CO_2-*eq*. However, after the study selection phase we found that such calculation models do not exist in the primary studies. Many studies examine the carbon footprint for a specific conference type by calculating the footprint based on one or multiple example conferences or are based on a field experiment [1, 2, 4, 6, 7, 8, 10, 16, 17, 21, 23, 24, 27].

Jäckle [17] uses an estimation approach to calculate the carbon footprint for the factor *Transportation* by using earlier studies like [7]. However, the authors are still using only a calculation method for travelling to conferences, and do not consider other examined factors like accommodation or catering. This highlights again the importance of the transportation category, especially air-traveling. Chalvatzis and Ormosi [5] analyze a large dataset of 263 economics conferences to provide a detailed travelling pattern. For **virtual** conferences, Faber [9] is the only author who proposes a generic and "modifiable framework for systematically measuring the emissions attributable to [virtual] conferences [by] using data about participant computers, Internet energy intensity, network data transfer, server power ratings, and other relevant factors."

D. RQ3 - On factors to increase a researcher's personal carbon handprint.

Regarding the **carbon handprint**, none of the primary studies considers the personal handprint [12] related to academic conferences. We also asked the interviewees about the carbon handprint of their conference attendees or an academic conference in general. None of the interviewees considered yet the handprint while organizing academic conferences; however, reacted positively and will consider certain handprint possibilities. One interviewee contributed that "healing starts with not breaking the environment in the first place".

We also considered **carbon offsetting**. Pierce et al. [26] compares carbon offsetting to taxes on everyday goods like "junk food" or other unhealthy products in the US. The authors claim that this kind of raising awareness lead to a "significantly reduced consumption" of such products. Hence, carbon pricing would reveal the "hidden environmental cost of emissions". However, the authors also claim that "carbon offsets and other 'good works' cannot substitute for real reductions in emissions: they are, at best, a short-term expedient that buys time to agree on more difficult cuts". This statement is also supported by [2, 21, 28, 34].

We adopted the classification of mitigation measures from Allegre et al. [1] and divided the extracted mitigation approaches into *local* and *international* mitigation measures. The former supports climate protection projects and organizations in the region where the conference is held, while the latter is aimed at international projects and organizations, since conference participants travel from all over the world to attend the conferences and thus generate emissions worldwide. For local mitigation, we found projects such as *Planting Trees* and *Hedgerow Groves* in [1, 14]. For international mitigation we elicited projects such as *Reforestation* [1, 2, 14, 21, 23, 26] and *Renewable Energy* [2, 14, 21]. Beyond these mitigation projects, Hamill [14] provides and discusses an extensive list of carbon offset providers.

The interviewees, in turn, already include offsetting programs in their planning strategy, *e.g.,*

- contributing to the Amazon Fund for Forest Conservation (local mitigation);
- granting a discount if a participant presents a certificate for environmentally friendly travel or offsets their emissions with a mitigation organization;
- raising awareness by planting trees together during socializing events.

E. Sustainability Factors

At an early stage of our research we identified a vivid discussion in the academic community about the trade-offs between the different conference types. The discussions are mostly about the disadvantages of on-site conferences and their associated carbon emissions through flying (c.f. RQ2), while virtual conferences suffer from the lack of social interaction caused by social distancing via video tools [2, 4, 10, 16, 26, 28]. Hence, instead of extracting and analyzing only the environmental impact, *i.e.,* the carbon footprint of an on-site, virtual, or hybrid conference, we also want to identify the trade-offs among the types. We extracted factors which do not have a direct impact on the carbon footprint and are not associated with carbon emissions in the first place. We name these factors *sustainability factors* and assign them to the four sustainability dimensions: (i) technical, (ii) economic, (iii) social, and (iv) environmental.

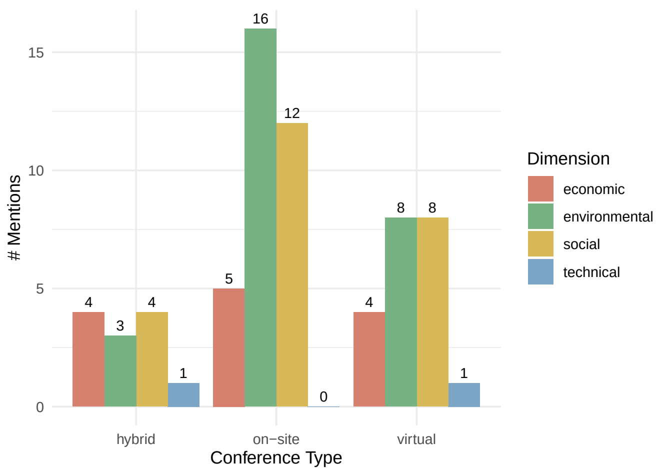


Fig. 6: Number of publications depending on conference type and sustainability dimension

Figure 6 summarizes the number of primary studies per conference type and sustainability dimension (without weighting). We can clearly see that environmental and social factors are discussed the most for on-site and virtual conferences since these two dimensions are also the most controversial dimensions. As environmental factors we reused the results from RQ1 and RQ2 since intrinsically the extracted factors have environmental characteristics and are related to the carbon footprint. The online available spreadsheet [3] outlines our results more in depth by including the weighting. The data were extracted as follows:

For each statement found in the data sources (*i.e.,* primary studies and interviews), we classified the statement according to a three-point Likert-scale: **+** positive (+1); **o** neutral (0); **-** negative (-1). For example, Jäckle [17] argues that gatherings help to build research networks and foster the exchange of ideas. According to our classification, this statement would be considered as the *on-site* factor *networking* with a *positive* Likert-value (+1) in the context of the *social dimension*.

To get a better understanding of what characteristics the different conference types have, we computed the statistical *MODE*. This calculation reveals the most frequent value for each sustainability dimension and provides the information about what strengths and weaknesses each conference type has for each sustainability dimension.

From the results, we can infer that **on-site** conferences have a positive effect in the social dimension by providing strong networking opportunities [5], [26], [24], [6, 23], [10], [4, 8, 16, 17, 28] and supportive cultural aspects [6, 10, 16, 17, 24] as well as academic citations [5, 8, 17, 24]. However, as revealed by our other research questions, the environmental impact, *i.e.,* the carbon footprint of on-site conferences is high and thus negative for the environment. In the **virtual** conference type, we observe the opposite. This type of conference has a positive impact on the environment by eliminating carbon emissions. Nevertheless, virtual conferences suffer from poor performance in networking and social activities [2, 4, 10, 16, 26, 28], although this conference type has a strong positive impact on inclusivity [2, 4, 5, 8, 16, 23, 28]. Inclusivity explains the opportunity for a wide range of participants to attend a conference. Scientific researchers in rural communities may find it difficult to afford conference fees and related travel activities such as airfare and lodging. Inclusivity also means that researchers have the opportunity to attend the conference who would not be able to do due to private issues such as family care-giving or disability. **Hybrid** conferences by contrast, offer positive impacts in both dimensions, environmental and social. The former are achieved by eliminating inter-continental flights and combining actual face-to-face interaction with video interaction.

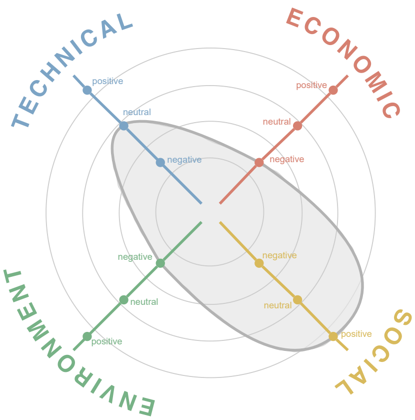
Regarding the economic dimension, our interviewees generally disagree with the literature. While conference fees and travel costs for virtual and hybrid conferences are considerably low compared to on-site conferences, our interviewees state that hybrid conferences in particular are “a nightmare to manage because you have to host a virtual conference in addition to the traditional on-site conference and you have to take care of the time zones and that both parts run synchronously”. Section VI provides a sustainability model to compare and contrast conference types according to their impact on each sustainability dimension.

VI. Discussion

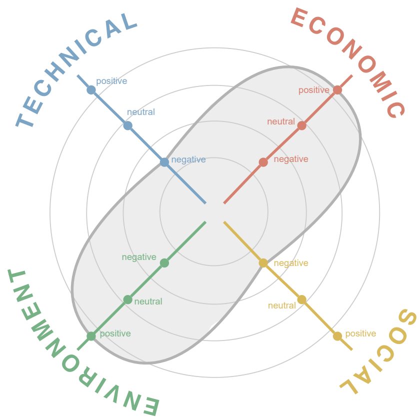
This study shows that even before the global COVID-19 pandemic occurred, there was a strong interest in the carbon emissions of academic conferences and the trade-offs between the different conference types. In this work, we complemented the literature with first-hand insights from international conference experts to analyze the three most discussed conference types for their carbon footprint factors, most influential factors, carbon handprint, carbon offsetting, and their sustainability impact. The difference between the conference types have lead us to uncover a variety of carbon footprint factors, categories and a sustainability model that visualizes the strengths and weaknesses of each type. Based on our findings, the following subsections discuss open research challenges, formalization of results in a reusable sustainability model, and possible future conference types.

A. Main observations

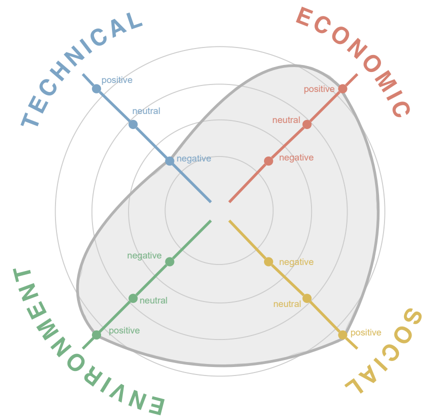
Carbon Footprint. As presented in Sections V-B and V-C, traditional on-site conferences suffer from a high carbon footprint caused by travel related factors; especially long-haul



(a) on-site



(b) virtual



(c) hybrid

Fig. 7: Sustainability Model

flights are one of the major contributors to carbon footprint. Hence, flying to international conferences as a factor cannot be neglected. The global pandemic has shown that virtual conferences are a valid option and that the overall footprint of such conferences can be significantly reduced [16], even though they require more ICT infrastructure related factors [9]. Although hybrid conferences are still not very popular, this conference type could reduce the carbon footprint significantly [16], *e.g.,* due to the elimination of intercontinental flights.

In this research, we created taxonomies for carbon footprint factors, *i.e.,* which factor relates to which conference type and in which higher-level category that factor can be grouped (c.f. replication package [3]). The results can be used by both conference organizers and participants to identify currently unconsidered factors and consciously discuss as well as address them when planning future conferences, and attending them.

To this aim, we could observe that no generic framework exists to measure the actual footprint of academic conferences. All primary studies examine the carbon footprint based on example conferences or a subset of past conferences. For virtual conferences we found a generic framework, which considers the most influential factors and calculates the carbon footprint of arbitrary virtual conferences. Since flying was identified as the most influential factor for on-site and hybrid conferences, almost each of the primary studies provide either an own calculation methodology for the carbon footprint of air-traveling or references to other approaches or online-calculators.

Research challenge 1: creating a generic framework that accounts for all revealed carbon footprint factors for each conference type.

Carbon Handprinting and Offsetting. As discussed in Section V-D, we were not able to find any primary study that considers carbon handprinting as an option for carbon care [1], *i.e.,* eco-friendly conferences. However, carbon offsetting is an already widely accepted methodology to reduce the carbon footprint of academic conferences. In this research, we provide an overview of publications that discuss offsetting in the context of academic conferences by reusing the categorization of Allegre et al. [1]. We do also mention several examples of mitigation options which are already used by conference organizers. This classification, along with the mitigation examples and the related discussion, can be used by conference organizers to consider whether or not to include a compensation plan in their next conference.

Research challenge 2: carbon handprinting as defined by Grönman et al. [12] should be considered while organizing academic conferences. If so, it would help create actions for carbon care conferences before carbon emissions are even released.

B. *Sustainability Model*

As presented in Section V-E, we were also interested in the trade-offs between different conference types. Hence, we extracted sustainability factors from our primary studies, grouped them into the corresponding sustainability dimensions, classified them by using a three-point Likert-scale, and computed the statistical MODE to get the most frequent value for each dimension. A visual representation of these numeric results is provided in Figure 7 which illustrates the sustainability models (inspired by spider plots). For each conference type we extracted the computed MODE (positive, neutral, negative) for all four dimensions and connected the dimensions with each other. A conference model which is balanced across all four sustainability dimensions would have a perfect circular shape. Since the outermost lane has the value positive, a circle expanding over the whole area of the diagram would indicate a perfectly balanced model that would have positive effects in all dimensions.

This model can be used to compare different conference types and examine their strengths and weaknesses in each sustainability dimension. As shown in Figure 7a, **on-site** conferences are strong in the social dimension, but weaker in the environmental and economic ones. A one-sided imbalance of the sustainability model is clearly visible. Compared to that, the **virtual** conference type in Figure 7b yields a diagonal oriented model indicating positive effects in the environmental and economic dimensions and signifying that the model falls short in the other two dimensions. Finally, the **hybrid** model depicted in Figure 7c is a blend of the former two models: it combines the positive social aspects of on-site conferences with the positive environmental and economic aspects of virtual conferences. However, due to the related technical challenges of such conferences, the technical dimension exhibits weaknesses.

The sustainability model described above, together with the numerical in-depth table (c.f. replication package), capture positive and negative features of different conference types in a detailed and accurate way. They can be (i) used as a decision-making tool for conference organizers of scientific conferences; and/or (ii) implemented more in-depth analysis of future conference types – as further discussed in the next section.

C. Future Conference Types

As mentioned in Section V-B, we were able to uncover a different interpretation for the hybrid conference type: **decentralized** conferences with multiple venues [4]. However, Orsi [24] argues that such conference type could outweigh footprint savings due to better accessibility of the venues and the accompanying higher number of participants ("rebound effect"). **Alternating** conferences, could also significantly reduce the carbon emissions of academic conferences [4, 14, 16] by alternating on-site and virtual every other year.

Even though novel conference types offer opportunities to reduce the conference's carbon footprint while preserving positive aspects of traditional conferences, one of our interviewees argued: "Before introducing new types of conferences, we should rethink our existing ones and perhaps consider a fundamental change in the conference system. If people travel to international conferences only to network, and only-partially listen to keynotes while distracted with emailing, we should consider holding only physical socializing events and move the talks and keynotes to virtual meetings."

VII. Threats to Validity

For the SLR search process, Kitchenham [19] proposes "to search [for] many different electronic sources". Nevertheless, only Google Scholar was considered as digital library for the SLR, making the database a single source of truth. However, as Martín-Martín et al. [22] observed, Google Scholar performs the best compared to Web of Science and Scopus. In addition, we performed a random cross-check to other databases like IEEE Xplore or ACM Digital Library while executing the initial search. These cross-checks showed that our Google Scholar search query included all publications resulting from the other databases. Nevertheless, we cannot exclude potential biases for the initial search.

As this study uses a mixed-method of an SLR complemented with interview surveys, we decided to limit our search queries to the TITLE field of the publication. This allowed us to both have relevant studies of different types and complement the results with the interview survey. It is possible that a resolution of this field restriction would have led to other relevant primary studies, however, it would have also decreased the quality due to the unrealistic large increase of irrelevant studies.

For the conducted interviews we consulted four steering committee members of three prominent international computer science related conferences. This relatively small number of participants might have led to a bias in the sample size. Furthermore, our interviewees only refer to the field of computer science or software engineering and the selection process was not based on a random selection. However, the intention of the survey was to complement the SLR by providing first-hand insights from experienced conference organizers. Of course, the results (like the classification of factors or the sustainability model) are domain-independent, and meant just as a starting point towards eco-friendly conferences.

VIII. Conclusion

This research provides an overview of academic literature across research domains that discusses the carbon footprint of academic conferences, specific carbon footprint factors, the most influential factors, and how carbon emissions can be mitigated through offsetting techniques. Our selected primary studies cover three envisaged conference types, namely on-site, virtual, and hybrid conferences. The literature findings, *i.e.,* the SLR results, are complemented by an interview survey among experienced organizers of international computer science related conferences.

Our main contributions include a reference list and taxonomy of carbon footprint factors related to the three conference types; a comparison of these three conference types according to their sustainability model; suggestions for organizing carbon care conferences; and a discussion about open research challenges.

We found that traveling by plane to an on-site conference is the most critical factor as well as the most discussed in the literature. A generic framework to compute the footprint beyond the factor *Transportation* for on-site conferences was not found. Our sustainability model compares the three conference types across four sustainability dimensions to visualize their trade-offs. In our vision, it can also be used to analyze future conference types and support decision making. Overall, our results can be used by academic conference organizers, to plan carbon care conferences, and raise awareness in their participants.

As future work, we intend to provide a "checklist" that can be used by organizers of academic conferences as guidelines to reduce the carbon footprint of conferences. As a groundwork, available checklists like in [27, 28, 34] can be used and enriched with our findings. In addition, our study is open for improvement by conducting a larger scale SLR to uncover more detailed factors together with related metrics. The results of such research can be used to provide a generic framework for calculating the carbon footprint of future conferences.

Acknowledgments

Special thanks go to Steffen Becker, Ruzanna Chitchyan and Grace Lewis for sharing their experience and insights.

References

[1] A. L. Allegre, S. Astier, A. Bouscayrol, L. Chevallier, X. Cimetiere, S. Clenet, B. Lemaire-Semail, P. Maussion, and J.-F. Sergent, "Experiences on Carbon Care Conferences," in *2014 IEEE Vehicle Power and Propulsion Conference (VPPC)*. Coimbra, Portugal: IEEE, Oct. 2014, pp. 1–6.

[2] L. Anderson and T. Anderson, "Online professional development conferences: An effective, economical and eco-friendly option," *Canadian Journal of Learning and Technology*, vol. 35, no. 2, May 2010.

[3] A. Anonymous, "Replication Package," Nov. 2021, accessed: 2022-01-25. [Online]. Available: https://anonymous.4open.science/r/SLR-Carbon-Footprint-replication-package-F7BA

[4] T. Bousema, P. Selvaraj, A. A. Djimde, D. Yakar, B. Hagedorn, A. Pratt, D. Barret, K. Whitfield, and J. M. Cohen, "Reducing the Carbon Footprint of Academic Conferences: The Example of the American Society of Tropical Medicine and Hygiene," *The American Journal of Tropical Medicine and Hygiene*, vol. 103, no. 5, pp. 1758–1761, Nov. 2020.

[5] K. Chalvatzis and P. L. Ormosi, "The carbon impact of flying to economics conferences: is flying more associated with more citations?" *Journal of Sustainable Tourism*, vol. 29, no. 1, pp. 40–67, Jan. 2021.

[6] V. C. Coroama, L. M. Hilty, and M. Birtel, "Effects of Internet-based multiple-site conferences on greenhouse gas emissions," *Telematics and Informatics*, vol. 29, no. 4, pp. 362–374, Nov. 2012.

[7] S. Desiere, "The Carbon Footprint of Academic Conferences: Evidence from the 14th EAAE Congress in Slovenia," *EuroChoices*, vol. 15, no. 2, pp. 56–61, Aug. 2016.

[8] B. Duane, A. Lyne, T. Faulkner, J. D. Windram, A. N. Redington, S. Saget, J. T. Tretter, and C. J. McMahon, "Webinars reduce the environmental footprint of pediatric cardiology conferences," *Cardiology in the Young*, pp. 1–8, Mar. 2021.

[9] G. Faber, "A framework to estimate emissions from virtual conferences," *International Journal of Environmental Studies*, pp. 1–16, Jan. 2021.

[10] M. Fois, A. Cuena-Lombraña, T. Fristoe, G. Fenu, and G. Bacchetta, "Reconsidering alternative transportation systems to reach academic conferences and to convey an example to reduce greenhouse gas emissions," *History and Philosophy of the Life Sciences*, vol. 38, no. 4, p. 25, Dec. 2016.

[11] P. Ghosh, A. Jha, and R. Sharma, "Managing carbon footprint for a sustainable supply chain: a systematic literature review," *Modern Supply Chain Research and Applications*, vol. 2, no. 3, pp. 123–141, Nov. 2020.

[12] K. Grönman, T. Pajula, J. Sillman, M. Leino, S. Vatanen, H. Kasurinen, A. Soininen, and R. Soukka, "Carbon handprint – An approach to assess the positive climate impacts of products demonstrated via renewable diesel case," *Journal of Cleaner Production*, vol. 206, pp. 1059–1072, Jan. 2019.

[13] S. Gössling, J. Broderick, P. Upham, J.-P. Ceron, G. Dubois, P. Peeters, and W. Strasdas, "Voluntary Carbon Offsetting Schemes for Aviation: Efficiency, Credibility and Sustainable Tourism," *Journal of Sustainable Tourism*, vol. 15, no. 3, pp. 223–248, May 2007.

[14] T. M. Hamill, "Toward Making the AMS Carbon Neutral: Offsetting the Impacts of Flying to Conferences," *Bulletin of the American Meteorological Society*, vol. 88, no. 11, pp. 1816–1819, Nov. 2007.

[15] M. Hicks, C. Lopes, and B. C. Pierce, "Engaging with Climate Change: Possible Steps for SIGPLAN," Preliminary Report of the SIGPLAN Climate Committee Version 1.3, 2021. [Online]. Available: https://docs.google.com/document/d/1VLIjocofEzDkjFBvHj3i7YeW9h14weWkG7DRw2e7f70

[16] S. Jäckle, "Reducing the Carbon Footprint of Academic Conferences by Online Participation: The Case of the 2020 Virtual European Consortium for Political Research General Conference," *PS: Political Science & Politics*, pp. 1–6, Feb. 2021.

[17] ——, "WE have to change! The carbon footprint of ECPR general conferences and ways to reduce it," *European Political Science*, vol. 18, no. 4, pp. 630–650, Dec. 2019.

[18] H. Karaosman, G. Morales-Alonso, and A. Brun, "From a Systematic Literature Review to a Classification Framework: Sustainability Integration in Fashion Operations," *Sustainability*, vol. 9, no. 1, p. 30, Dec. 2016.

[19] Kitchenham, "Guidelines for performing systematic literature reviews in software engineering," Keele University and University of Durham, UK, EBSE Technical Report 2.3, 2007.

[20] P. Lago, S. A. Koçak, I. Crnkovic, and B. Penzenstadler, "Framing sustainability as a property of software quality," *Communications of the ACM*, vol. 58, no. 10, pp. 70–78, Sep. 2015.

[21] R. N. Mankaa, M. Bolz, E. Palumbo, S. Neugebauer, and M. Traverso, "Walk-the-talk: Sustainable events management as common practice for sustainability conferences," *12th Italian LCA network conference*, pp. 11–12, 2018.

[22] A. Martín-Martín, E. Orduna-Malea, M. Thelwall, and E. Delgado López-Cózar, "Google Scholar, Web of Science, and Scopus: A systematic comparison of citations in 252 subject categories," *Journal of Informetrics*, vol. 12, no. 4, pp. 1160–1177, Nov. 2018.

[23] K. Milford, M. Rickard, M. Chua, K. Tomczyk, A. Gatley-Dewing, and A. J. Lorenzo, "Medical conferences in the era of environmental conscientiousness and a global health crisis: The carbon footprint of presenter flights to pre-COVID pediatric urology conferences and

a consideration of future options," *Journal of Pediatric Surgery*, Jul. 2020.

[24] F. Orsi, "Cutting the carbon emission of international conferences: is decentralization an option?" *Journal of Transport Geography*, vol. 24, pp. 462–466, Sep. 2012.

[25] D. Pandey, M. Agrawal, and J. S. Pandey, "Carbon footprint: current methods of estimation," *Environmental Monitoring and Assessment*, vol. 178, no. 1-4, pp. 135–160, Jul. 2011.

[26] B. C. Pierce, M. Hicks, C. Lopes, and J. Palsberg, "Conferences in an era of expensive carbon," *Communications of the ACM*, vol. 63, no. 3, pp. 35–37, Feb. 2020.

[27] P. Z. Ruckart, C. Moore, D. Burgin, and M. K. Byrne, "The 2009 National Environmental Public Health Conference: One Model for Planning Green and Healthy Conferences," *Public Health Reports*, vol. 126, pp. 58–63, May 2011.

[28] J. D. Sherman, "COVID, Climate Change, and Carbon-Neutral Medical Conferences," *ASA Monitor*, vol. 85, no. 1, pp. 22–23, Jan. 2021.

[29] United Nations, "The UN Sustainable Development Goals," 2021. [Online]. Available: https://sdgs.un.org/goals

[30] M. Y. Vardi, "Reboot the computing-research publication systems," *Communications of the ACM*, vol. 64, no. 1, pp. 7–7, Jan. 2021.

[31] S. Wynes and K. A. Nicholas, "The climate mitigation gap: education and government recommendations miss the most effective individual actions," *Environmental Research Letters*, vol. 12, no. 7, p. 074024, Jul. 2017.

[32] Y. Xiao and M. Watson, "Guidance on Conducting a Systematic Literature Review," *Journal of Planning Education and Research*, vol. 39, no. 1, pp. 93–112, Mar. 2019.

[33] J. Zhang, X. Qian, and J. Feng, "Review of carbon footprint assessment in textile industry," *Ecofeminism and Climate Change*, vol. 1, no. 1, pp. 51–56, Jun. 2020.

[34] O. Zotova, C. Pétrin-Desrosiers, A. Gopfert, and M. Van Hove, "Carbon-neutral medical conferences should be the norm," *The Lancet Planetary Health*, vol. 4, no. 2, pp. e48–e50, Feb. 2020.