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A community-guided discussion about social and environmental effects of post-COVID-19 Computer Science conferencing

Danilo Carastan-Santos¹ Krzysztof Rządca² Leonel Sousa³
Denis Trystram¹

¹Univ. Grenoble Alpes, CNRS, Inria, Grenoble INP, LIG
danilo.carastan-dos-santos@inria.fr, denis-trystram@imag.fr

²University of Warsaw
krzadca@mimuw.edu.pl

³INESC-ID, Instituto Superior Técnico, Universidade de Lisboa, Portugal
las@inesc-id.pt

Abstract

Conferencing is one of the main pillars of Computer Science research activity regarding career and networking, with conference publications playing a more pronounced role compared to other disciplines. The COVID-19 pandemic forced us to switch to virtual conferencing, and many works have shown the benefits of virtual conferencing in terms of inclusivity and reduction of Green House Gas emissions. We are moving toward the usual conferencing format as it appears that the pandemic is increasingly under control. However, the changes imposed during the period of the pandemic brought many essential lessons regarding conferencing social and environmental effects. A crucial task is to gather these community experiences to give directions on how to keep the learned lessons post-COVID-19. We used the Euro-Par conference to synthesize these lessons in the Computer Science case. We show practical results that reinforce the marginal emissions of virtual conferencing compared to in-person conference travel. We also open the debate that rethinking the conference utility according to our objectives (scientific and ecologic) and being aware of social/geographical biases are essential factors in participating and organizing post-COVID-19 conferences.

1 Introduction

Global warming is one of humanity’s most critical challenges due to the ever-increasing greenhouse gas (GHG) emissions from human activities, in which aviation contributes up to 3.5% [17] of total global emissions. The Computer Science (CS) scientific community has played its part in these emissions as it has relied on frequent international conferences, often requiring intercontinental travel. Conferences are a traditional part of the CS community since it considers conferences as the main communication channel for research results [6, 11]. In CS conferences, articles pass peer-review and present original research results. Prestigious conferences can reach acceptance rates lower than 20%. CS researchers tend to start their careers, publish more papers, and collaborate with more coauthors in conferences than in journals [20].

The shift to virtual conferencing enforced by the COVID-19 pandemic has thrown the scientific community (and especially the CS community) in a drastic change in the mode of operation, but it also has reintroduced the debate about the ecological impacts of in-person conferencing [30, 18, 29, 9]. Shifting to a fully virtual conference format can reduce GHG emissions by up to 99% [22].

Moreover, the CS community, although quite reactive to the change from in-person to virtual [24], is arguably more sensitive to this change. Conferences are more important to build a career in CS (in terms of publication records, sharing research results, networking, *etc.*) than in other disciplines, making it important to understand the community view of the shift from in-person to virtual.

This paper is a step towards better understanding these points by presenting a community-guided discussion to understand the environmental effects of post-COVID-19 Computer Science conferencing. We took as a use case the 2020 and 2021 editions of the International European Conference on Parallel and Distributed Computing (Euro-Par). Euro-Par represents a typical CS conference: over more than 25 years, it developed a robust, active community of researchers; gathering annually approximately 200 in-person participants. The 2020 and 2021 editions took place virtually. Our community-guided method consists of (1) estimating the CO2 emissions of the conference, and we compared them to a hypothetical fully in-person conference; (2) presenting these estimations to the conference’s community to foster feedback and comments; and (3) using these comments and feedback to guide our discussions and analyses.

The two key new methodological contributions of this paper are: first, approaching the environmental effects of post-COVID-19 Computer Science conferencing under the particular perception of the CS community; and, second, by approaching the community as an integral part of the study methodology, by tailoring a community-guided discussion on the matter.

There is a rapid increase in the number of studies regarding this shift from in-person to virtual/hybrid conferencing. Most studies focus on its environmental impacts, in terms of CO2 equivalent emissions. Prior works [30, 18, 9] took into account the transport and the electricity consumption of devices and servers emissions. Tao *et al.* [29] performed a Life Cycle Assessment (LCA) including food, accommodation, preparation, execution, information and communication technology, and transportation of an in-person, virtual and hybrid conference. Their carbon footprint estimations acknowledged the previous works, showing that participants’ transport dominates the emissions of an in-person conference, accounting for more than 80% of the total emissions. These works considered the carbon intensity of electricity generation in the virtual conference emissions by using either a single value [9] or min-max values, that work as a lower and upper bound of the emissions [18]. The aforementioned works also consider only one method for estimating the emissions of conferencing. We distinguish from these works by using multiple virtual conference GHG emission models during our evaluation, taking into account the carbon intensity of electricity generation of the conference hosting and participant’s country.

Numerous works considered multi-site/hybrid conferences as an in-between alternative for conferencing. The major question in this scenario is to decide on how many hubs to launch and where to place them. Choices are from arbitrary [30, 13], to driven by optimization methods with criteria such as potential emissions [28] and geometric distance of participants [4]. Tao *et al.* [29] introduced two criteria for selecting hub locations, Maximum Virtual Participation and Maximum Travel Distance. While all these works show significant reductions in energy consumption and GHG emissions, — geographical social effects of conference hub locations are neglected. In contrast, we debate possible social effects of such decisions.

Our work distinguishes from others in the literature in the following factors: (i) we use multiple virtual conference GHG emission models during our evaluation, taking into account the carbon intensity of electricity generation of the conference hosting and participant’s country, (ii) to the best of our knowledge, we are the first study to evaluate the GHG emissions of virtual and in-person conferences in

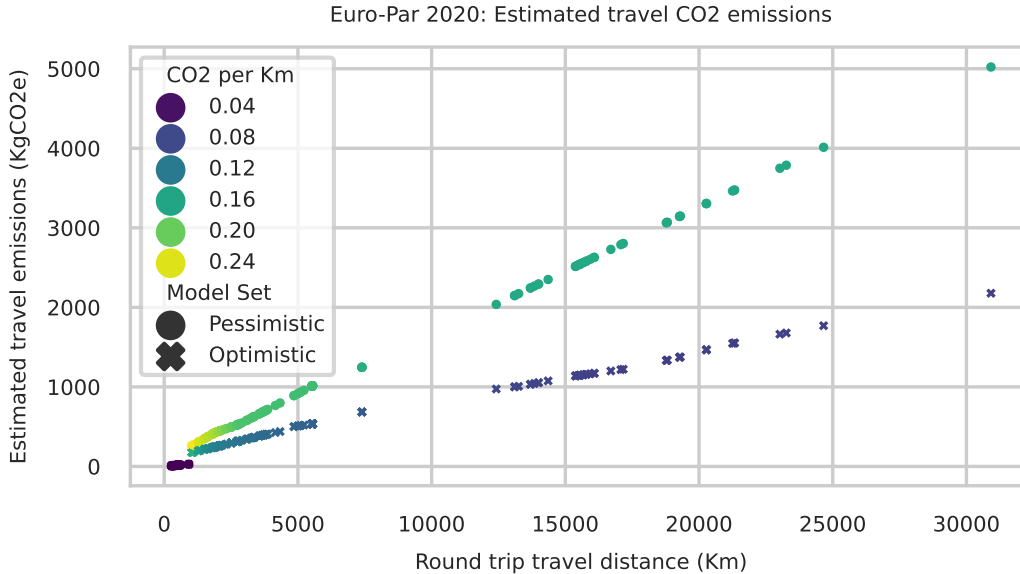


Figure 1: Per participant travel emissions estimations for Euro-Par 2020

Computer Science, which has a greater impact on the scientists’ careers as abovementioned, and (iii) we approach the Computer Science community as an integral part of the study methodology, by tailoring a community-guided discussion on the problem.

2 Results

We had access to Euro-Par 2020 and 2021 participant data collected by their respective videoconferencing software. The data available were the declared participant’s city (manually inferred from the participants’ affiliation) and country data, and participation in the conference’s sessions. For Euro-Par 2020, we had precise information about the number of login hours for each participant and each session, and we used this information to calculate the number of participation hours for each participant. For Euro-Par 2021, we had only the information of whether a certain participant logged in to a certain session. In this case, we calculated the number of participation hours for a participant by summing the number of hours for each of the sessions this participant logged in.

After this pre-processing, we had participant data for 221 and 137 participants for Euro-Par 2020 and 2021, respectively. This discrepancy in attendance data is due to the free registration and attendance of Euro-Par 2020, whereas such registration and attendance were paid for Euro-Par 2021.

For the collaborative part of the methodology, we made a presentation at the “miscellaneous” session at Euro-Par 2022, which was a hybrid event hosted in Glasgow, UK. There were roughly three times more people attending the sessions in-person than attending on-line.

2.1 Emissions estimations of Euro-Par

2.1.1 Travel emissions estimations

In this section we present the estimated, hypothetical travel emissions for Euro-Par 2020 and 2021. For each of these editions we performed two estimations (i) one estimation that averages estimations of three models: MyClimate [25], ADEME [1] and DEFRA [10] (the *pessimistic* models category, see Section 4.1.1) and (ii) one estimation that averages estimations of three other models: ICAO [14], KLM [21] and the French Ministry for the Ecological and Inclusive Transition [26] (the *optimistic* models category, see Section 4.1.1). We also set a threshold value of 500 km to define if a certain travel distance can be performed by train.

Figures 1 and 2 show the CO2 travel emissions estimations for Euro-Par 2020 and 2021, respectively, using the pessimistic and optimistic model sets. For a certain model set, each point in a figure represents a participant. The CO2 emissions estimations consider the distance of a round trip between the

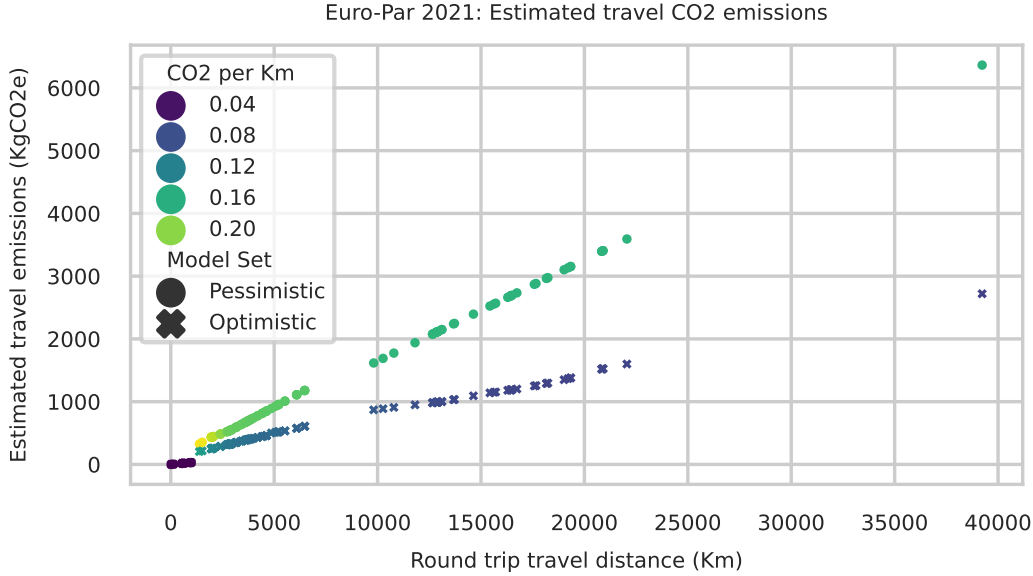


Figure 2: Per participant travel emissions estimations for Euro-Par 2021

Table 1: Travel CO2 emissions estimations for Euro-Par 2020 and 2021.

Year	Model Set	Estimated Emissions (kgCO2eq)	Equivalent Emissions (U.S. homes' energy use for one year [3])	Equivalent to Carbon Sequestered by (m^2 of U.S. forests in one year [3])
2021	Pessimistic	$1.73 \cdot 10^5$	21.8	$8.30 \cdot 10^5$
2021	Optimistic	$8.46 \cdot 10^4$	10.7	$4.05 \cdot 10^5$
2020	Pessimistic	$2.14 \cdot 10^5$	27	$1.02 \cdot 10^6$
2020	Optimistic	$1.06 \cdot 10^5$	13.4	$5.10 \cdot 10^5$

participants' city and Euro-Par's host city (Warsaw for 2020 and Lisbon for 2021), and the participant's travel emissions per kilometer is represented by the marker's color. Participants are sorted in increasing order of their round trip travel distance. Table 1 shows the total travel CO2 emission estimations for Euro-Par 2020 and 2021.

The emissions curves in Figures 1 and 2 present two parts. The first represents participants whose travel was considered to be by train – whose emissions are estimated similarly for both model sets, and we can identify this part by the left-most, violet-colored cluster of points in the figures. The second represents participants whose travel was considered to be by plane (the remaining points). Both model sets show the same tendencies of CO2 emissions. The difference lies on how faster the emissions increase in function of flight distance, with the pessimistic model increasing faster. Due to the multiplicative RFI factor of around 2, by looking at Table 1 we observe that the pessimistic model set estimated around twice as much total CO2 emissions than the optimistic model set.

On one hand, as expected, the longer the travel distance, the higher is the CO2 emissions. On the other hand, longer trips are more efficient in terms of CO2 emissions per kilometer. Figures 1 and 2 show that in both model sets, flights within short distance (round trip distance between 1000 km and 2500 km) result in higher emissions per kilometer when compared to longer flights in the same model set.

For contextualizing these emission numbers in Table 1, we also show some equivalent numbers that correspond to the estimated CO2 emissions [3], notably the number of United States homes energy use for one year – to put into perspective the energy consumption – and the number of square meters of United States' forests for one year – to put into perspective how much forest area is required to sequester the emitted CO2. The emissions can reach up to an equivalent of 27 houses' emissions during one year. The forest area needed to sequester the emitted CO2 reaches up to a size equivalent to 143 soccer fields ($7140 m^2$).

Table 2: Values used for the parameters in the extended Burtscher *et al.* method.

Parameter	Value
$bdwth$	4.21 Gb/h
kWh_{Gb}	0.0075 kWh/Gb
$devpwr$	0.03 kW
$serpwr$	0.3 kW

Table 3: Virtual Euro-Par CO2 emissions estimations

Year	Method	Emissions (kgCO ₂ eq)				Equivalent to Carbon Sequestered by (m ² of U.S. forests in one year [3])
		Laptop	Network	Server	Total	
2021	Extended IEA	9.26	6.48	1.74	17.50	84.98
2020	Extended IEA	9.07	9.19	3.591	21.86	105.21
2021	Extended Burtscher <i>et al.</i>	12.63	11.27	3.73	27.64	133.54
2020	Extended Burtscher <i>et al.</i>	12.37	15.99	12.16	40.53	194.24

2.1.2 Virtual emissions estimations

In this section we present the CO₂ emissions estimations of the virtual Euro-Par 2020 and 2021, taking into account the extended IEA and Burtscher *et al.* methods presented in Section 4.1.2. We considered the “Laptop, Wi-Fi, HD” for the former method since it is the closest scenario to a typical virtual conferencing configuration. For the latter method, we used the parameters presented in Table 2. For both methods, we used the carbon intensity of electricity generation data provided by the European Environment Agency (EEA)¹. If we can not find carbon intensity of electricity generation for a certain participant’s country using EEA data, we used the world average of 475 gCO₂/kWh [15].

Table 3 shows the estimated CO₂ emissions for the virtual Euro-Par 2020 and 2021. The estimated emission for a virtual conference is *three orders of magnitude lower* than the in-person equivalent (see Table 1). We can also notice the discrepancies in the emissions when comparing the two models, with the Extended Burtscher *et al.* model estimating almost twice more emissions as the Extended IEA. This discrepancy between models can be problematic if one wants to evaluate different virtual conferencing configurations and grasp potential benefits, though this discrepancy is less relevant for qualitative studies comparing virtual and in-person conferencing, which is the case in this paper.

2.2 Euro-Par community community-guided discussion

We synthesized the comments and feedback obtained during the discussion panel held during Euro-Par22 in the topics below.

2.2.1 Virtual participation incentives and inclusivity tradeoffs

Numerous comments were on the introduction of the hybrid conference format and incentives to foster virtual participation.

“If we make on-line attendance considerably cheaper than in person this would encourage people to adopt this route”

“COVID shone a light on huge opportunities for making academic conferences more accessible than they were. PhD students and researchers who don’t have travel budgets from under-represented institutes and countries were attending events in 2020 and 2021. ... I urge steering committees at conferences like EuroPar to not push for a return to the pre-2020 days: remote participation should be free for non-authors. It would be tragic if remote participation is actively disincentivized by deliberately raising the cost of remote participation to encourage physical attendance, because steering committees decide that physical interactions are essential. Quite the opposite, physically attending delegates should be charged a surcharge to buy carbon credits to make these conferences carbon net-zero. Institutes that can afford to send their people to conferences at thousands of EUROS are very likely able to afford an extra +5% for carbon credits.”

¹<https://www.eea.europa.eu/api/SITE/data-and-maps/daviz/co2-emission-intensity-9/download.csv>

“... Encouraging people to attend virtually with incentives like cheap admissions costs are a quick and easy way to promote this behavior. It is also a low cost burden on the conference hosts as well”

“Some senior members of the community are concerned that virtual attendees with ‘cannibalize’ (i.e. reduce) in-person delegates. It seems that the Euro-Par’22 experience suggests that this is not the case.”

To our interpretation, the hybrid model introduced during the COVID-19 pandemic has brought benefits for certain members of the Euro-Par community, especially for those who do not have enough travel budgets from their institutions, or for those who want to follow the virtual conferencing mode to reduce the emissions from their activities.

However, the high cost to participate in a hybrid conference virtually hinders the realization of these benefits. For instance, a presenting author wanting to participate only at the Euro-Par 2022 main conference (and not the workshops) would pay 370 euros or 310 euros for in-person or virtual participation, respectively². We can not distinguish if the discrepancy between in-person and virtual attendance is due to the lack of interest or due to the lack of registration incentives for participating in virtual. We conjecture that this is possibly tied to individual perceptions regarding the purpose of a conference, which we elaborate on in the next section.

A possible measure to increase virtual participation is reducing the cost. Given the magnitude of the conference participation (i.e., a few hundred participants in the Euro-Par use case), increasing virtual participation results in a marginal increase in Information and Communications Technology (ICT) CO₂ emissions, especially compared to popular activities such as video streaming. Yet, the energy consumption of ICT increases up to 9% per year [27], with a global share of emissions of around 3% [12]. ICT emissions are in the same order as the aviation industry [17].

We can mitigate the virtual conferencing energy consumption with frugal technologies such as replacing video streaming during presentations with lightweight presentations consisting of local slides (PDF files) synchronized with the presenter’s audio. However, we must not hinder the quality of remote participation (e.g.: low-quality streams leading to increased fatigue). Frugal virtual conferencing technologies must achieve the highest level of virtual conferencing experience with the lowest energy consumption and required infrastructure.

A solution supported by the *Labo 1point5* initiative in France³, though arguably coercive, is to impose emissions control in the research laboratories by assigning carbon emission budgets for the activities, which includes conferencing. With such a budget strategy, however, laboratories may seek to blindly optimize their emissions which may deepen the difficulties of performing research activities for specific demographics, going against inclusivity. An example is caretakers: persons in charge of small children or the elderly are likely unable to afford the extra travel time of using low-carbon transportation (trains) and/or will need to bring the children or the elderly with them. In a caricatural scenario, a laboratory seeking to optimize its emissions would always fund three young/late-career men by train to go to three different conferences than a woman with two children to a single conference.

2.2.2 Purpose and effectiveness of virtual Euro-Par

Comments regarding the purpose and effectiveness of the virtual editions were raised.

“... maybe many people are keen to experience in-person events again after 3 years of Covid lockdowns?”

“Should we normalize these by the ‘effectiveness’ of in-person vs. virtual? In the past 3 years, I have paid for several virtual conferences which I never ended up attending because I couldn’t get away from my normal commitments at home (e.g., teaching, meetings, etc.).”

Although it is commonly agreed on by the Computer Science community that the main purpose of a conference is to share scientific results, one may perceive the main purpose as being the paper published at a prestigious event, or as being the opportunity to meet the community and to do networking, or to have an update on what subject are being studied by the community.

Meeting colleagues and networking is arguably the hardest to achieve with the current virtual technology. Current virtual conferencing technology misses transmitting non-verbal attitudes that say as

²<https://2022.euro-par.org/attending/registration/>

³<https://labos1point5.org/>

much as words. We feel psychological subtleties better when interacting in-person, and, therefore, we advance quicker in interchanging research ideas and building professional networks when participating in an in-person conference. Moreover, in-person conferencing activities such as coffee breaks, cocktails, and other side social events foster social interactions more naturally than in virtual. Achieving this purpose by participating in person comes at the cost of increased emissions due to travel.

We can nevertheless employ actions to value these emissions by, for instance, promoting extended stays for long-distance conference participants, with the goal of maximizing the research collaboration opportunities with the local researchers. Such an idea was employed at the 2022 edition of the International Colloquium on Automata, Languages and Programming (ICALP)⁴, one of the main events in the theoretical computer science community. Informally, the idea is to “batch” the research activities with an extended stay in a institution local to the conference, potentially avoiding multiple long-distance trips, and resulting in fewer emissions overall.

Virtual conferencing can be hard to follow for other practical reasons, such as difficulties with significant timezone differences, or lack of dedicated time for conferencing.

2.2.3 Influence of the location: Host city and multi-hub

Comments were raised regarding the geographical location for future Euro-Par editions.

“Since Euro-Par is a European conference and CO2 emissions are dominated by flights, I think they could be reduced considerably by hosting most future conferences somewhere in central Europe. This is a big incentive for a large portion of attendees to come by train instead.”

The choice of the host city is an important parameter to mitigate the emissions. A possible approach to reduce emissions from conferencing is to decide on a host city that is more accessible by train to *most* participants. We can devise, for instance, algorithms that look at the attendant’s geographic distribution of previous editions to decide where to host the next edition of a conference. Although this approach could be efficient in terms of CO2 emissions, it also has the potential counterpart of increasing the geographical bias of research, since it is very likely that institutions in the same region – i.e., a centrally-located region with an efficient train network – would be selected every year.

A trade-off solution that is currently being considered by some communities is a multi-hub conference format [30, 29] taking into account the constraint of avoiding too many moves of people working in far countries. However, most related studies in multi-hub conferencing format transmit geographical biases in the analysis results. Algorithms are created upon biases, and the algorithms institutionalize these biases and all issues that follow, ending up with statements such as “a conference located in the southern hemisphere usually performs much worse in terms of the carbon footprint than the northern hemisphere” [29]. Most works propose algorithms and solutions whose results center in the Northern Hemisphere, notably in the US/Europe axis, overlooking the fundamental issue of the international inequality of research, which risks being self-reinforced. We argue that it is the political responsibility of the scientific communities to foster some countries, working towards global inclusivity of research, while also being aware of reducing CO2 emissions.

Even within the US/Europe axis, we risk transmitting geographical biases. For instance, we could evaluate and propose algorithms for optimized/optimal placements of a virtual conference according to the carbon intensity of electricity generation (i.e., energy mix) of the hosting country. However, such contributions would be based upon a more fundamental issue, which in this case is inequality between countries in terms of technology, economy, and access to natural resources (wind, rivers, etc.) to produce low-CO2 electricity. For the above reasons we deliberately decided not to analyze, propose solutions, and provide results regarding the origin country of the participants.

Moreover, it is hard to detach any conference location optimization algorithm, on both single or multi-hub, to indirect or direct rebound effects. For instance, an algorithm that decides the conference location according to the energy mix of the hosting country may lead to an overexploitation of the country’s energy, eventually usurping the energy of an essential service. A possible approach to avoid the rebound effect pitfall is, as advocated in [23], introducing the concept of limits as an integral part of the constraints and specifications of the methods. Applying this concept of limits could be, for instance, by creating methods assuming by design that the availability of low-CO2 energy in a particular country will not grow accordingly.

⁴https://icalp2022.irif.fr/?page_id=50#support

3 Discussion

Our work is a step towards better understanding the challenging endeavor to solve the fundamental issue of reducing the greenhouse gas (GHG) emissions of research activities, more specifically in Computer Science conferencing. The COVID-19 pandemic forced us to move towards virtual activities, and this has put into evidence once again the debate of whether to move conferences to virtual, in order to reduce their environmental impacts.

We have taken the opportunity of the changes in our behavior imposed by the COVID-19 pandemic to investigate a concrete case, the effects of the remote conferences on the 2020 and 2021 editions of the European Conference on Parallel and Distributed Computing (Euro-Par), which took place virtually. We made extensions to current methods to estimate virtual conference emissions, and we used them to study the impacts of electricity consumption of terminals and networks of Euro-Par 2020 and 2021. We compared these estimations of the virtual Euro-Par to emissions estimations of traveling as if Euro-Par 2020 and 2021 took place in person. We then presented these emissions estimations at Euro-Par 2022 to build a Euro-Par’s community-guided discussion on the matter.

This work reinforces the qualitative result that virtual conferences are several orders of magnitude less pollutant than in-person conferences. The comments and reactions of the Euro-Par community were positive on the matter, indicating a positive attitude from the community towards reducing Euro-Par environmental impact.

In summary, the introduction of virtual participation increased the inclusivity of the scientific results. We suggest deploying registration incentives for virtual registration to keep this inclusivity post-COVID-19. We observe that this increase in inclusivity comes at a marginal cost of increasing the demand for information and communications technology (ICT). Still, developing and deploying frugal virtual conferencing technologies that achieve the highest level of virtual conferencing experience with the lowest energy consumption and the required infrastructure is essential to keep the cost of virtual conferencing marginal.

We also observed that the current virtual conferencing experience could be more or less valuable according to the purpose of the participant. Social and networking interactions are currently more effective by participating in person, with the drawback of increased emissions. We should reinvent the current way we work and collaborate by, for instance, establishing a ratio of benefit (purpose) versus environmental effects of participating in a conference. We establish this ratio by knowing the purposes we want to achieve when participating in a conference and what environmental effects result in achieving such objectives.

We finally emphasized the complex objective of minimizing the environmental impacts of a conference, while not passing forward more fundamental social issues, especially the global inequality in research. This objective is especially hard when considering optimizing the conference’s host location or the conference’s location in a multi-hub scenario. We claim that future research on conference host and multi-hub locations must be aware of these social issues when proposing new methods.

4 Methods

We divide our method into two steps. The first step involves using the conference participant’s data to estimate the emissions of a conference. This first step gives qualitative and quantitative estimations of the environmental effects of a conference, but their interpretations and possible measures rely on collective knowledge from the conference’s community. We address this in the second step, where we build a mechanism to collect feedback from the conference community to tailor a community-guided discussion.

4.1 Step 1: Estimating CO2 emissions of a conference

4.1.1 Estimating in-person travel CO2 emissions

Although many factors add up to the CO2 emissions of an in-person conference, such as hotels, or meals, traveling is arguably the most important factor, accounting for around 85% of the total carbon footprint [29]. To estimate the conference participants’ travel CO2 emissions, we used an online travel footprint calculator [7]. This calculator estimates the travel footprint associated with round-trip flights. The advantage of this calculator is that it incorporates models obtained through numerous flight emissions data sources. The data sources are:

- ADEME [1]: the French Environment and Energy Management Agency Carbon database;
- The French Ministry of Ecology and Inclusive Transition [26];
- atmosfair [5], a German Carbon offsetting non-profit organization;
- DEFRA[10], UK’s Department for Environment, Food and Rural Affairs;
- ICAO [14], a widely known online calculator;
- KLM [21] Carbon compensation service data;
- myclimate [25], a Carbon offsetting non-profit organization.

Among other factors, these sources differ in how they deal with the radiative forcing index (RFI) [19], which is a multiplicative factor for aircraft CO2 emissions that accounts for the increased effects such as burning fuels directly into the upper/lower stratosphere and aviation induced cloudiness introduced by contrails [8], impacting atmospheric composition. Setting an appropriate value for the RFI is an ongoing debate in the community. Commonly used RFI values are 1 (no RFI), which is the case for the French Ministry of Ecology and Inclusive Transition, KLM, and ICAO, 1.9 for DEFRA, 2 for myclimate and ADEME, and 3 for atmosfair.

We can have some variability of the estimations by considering multiple estimation methods. For our estimates, we defined two categories of models: (1) the *pessimistic* models: the ADEME, myclimate, and DEFRA models; and (2), the *optimistic* models, the French Ministry of Ecology and Inclusive Transition, KLM and ICAO models. We report the corresponding models’ CO2 emissions for each category as an average. The used online travel footprint calculator also enables us to evaluate the emissions related to train journeys by setting a threshold distance for flying. When a distance of a certain participant is lower than this threshold, the calculator switches from air to train travel, and CO2 emissions are estimated accordingly.

The calculator requires two inputs, an *origin* input, and a *destination* input. The *origin* input can be a CSV file where each line contains a city and country of a participant, and the *destination* input is the city and country of the conference. For the *origin* file, each participant must correspond to a line in the CSV file. The calculator then groups the number of entries per city/country and reports the sum of CO2 emissions of a round trip for all participants from each city/country. The calculator assumes that each participant takes an independent flight and no other participant takes the same flight, acting, therefore, as an upper bound for the number of flights.

4.1.2 Estimating virtual conference CO2 emissions

We made extensions into two distinct methods for estimating the CO2 emissions of a virtual conference and streaming video. Both methods consist of multiplicative models, the overall difference between them is which kind and source of data are considered.

First method: extended IEA video streaming emissions. We developed a method of measuring the CO2 emissions of a virtual conference, by making extensions to a study performed by IEA [16], that estimates the consumed energy in kilowatt-hour of streaming video. An assumed hypothesis is that a streaming video interaction corresponds to most of the current virtual interactions in virtual conferences (including Euro-Par 2020 and 2021).

IEA’s study provides energy consumption estimations for three different scenarios, considering different viewing device choices, types of network connection, and video resolution. The baseline IEA method for estimating CO2 emissions of streaming video works as follows: for a scenario S , the CO2 emissions of a person p watching a video for one hour can be estimated by the following equation,

$$CO2_p = (kWh_{ser}(S) + kWh_{net}(S) + kWh_{dev}(S)) \cdot CI \quad (1)$$

where $kWh_{ser}(S)$, $kWh_{net}(S)$, and $kWh_{dev}(S)$ are the energy intensity of the server, network, and viewing device of a person watching a one-hour video, taking into account the scenario S – such values are provided by IEA’s study [16] – and CI is a value of carbon intensity of energy generation, that measures how much CO2 is emitted when producing electricity.

We extended the above baseline in the following manner: we changed Equation 1 to account for the number of participation hours and the heterogeneity in the carbon intensity.

$$CO2^p = (CI_{ser}kWh_{ser}(S) + CI_{net}kWh_{net}(S) + CI_p kWh_{dev}(S)) \cdot nbhours^p \quad (2)$$

In this extension (Equation 2), $nbhours_p$ is the number of participation hours for participant p and CI_{ser} , $CI_{net} = \frac{CI_{ser} + CI^p}{2}$, and CI_p are the carbon intensity of electricity generation for the server, network, and viewing device components. For the former, such data can be easily retrieved in standard videoconferencing software such as Zoom. For the latter, such information can be found on websites such as Electricity Map⁵, or the European Environment Agency (EEA) [2]. The change in the carbon intensity is to account for differences in the carbon intensity of electricity generation according to the geographical location of each of the components: CI_{ser} and CI_p are the carbon intensity of electricity generation where the server and the participant are located, respectively, and CI_{net} is an estimation of the carbon intensity from the server to the participant location.

Finally, total CO2 emissions of a virtual conference taking into account a list of participants \mathcal{P} can be estimated using Equation 3.

$$CO2_{total} = \sum_{p \in \mathcal{P}} CO2_p \quad (3)$$

Second method: extended Burtscher *et al.* emissions of virtual conference. We extended Burtscher *et al.* [9] method to estimate the carbon emissions of a virtual conference. This method first estimates the energy consumption of the ICT infrastructure in terms of network, end devices, and server, and then converts the energy consumption to respective carbon emissions. In this section, we first present its baseline version, and then we present our extended version.

The baseline method first estimates the overall participant demand dem during the conference,

$$dem = nbdays \cdot onlinenbhours \cdot att \cdot nbpart \quad (4)$$

where $nbdays$ is the number of conference days, $onlinenbhours$ is the number of hours that the participants stayed online per day, att is a daily attendance percentage of the total of participants, and $nbpart$ is the total number of participants.

After estimating dem , then the method estimates the carbon emissions of network $CO2_{net}$, end device $CO2_{dev}$ and server $CO2_{ser}$, and then finally estimates an overall carbon emission of the conference $CO2_{total}$ (Equation 5).

$$\begin{aligned} CO2_{net} &= dem \cdot bdwth \cdot kWh_{Gb} \cdot CI \\ CO2_{dev} &= dem \cdot devpwr \cdot CI \\ CO2_{ser} &= nbdays \cdot nbhours \cdot serpwr \cdot CI \\ CO2_{total} &= CO2_{net} + CO2_{dev} + CO2_{ser} \end{aligned} \quad (5)$$

In the equation above, $bdwth$ is the necessary network bandwidth per participant, kWh_{Gb} is the energy intensity of the network per Gigabit, $devpwr$ is the power of the end viewing device, $nbhours$ is the number of hours per day that the server was online, $serpwr$ is the server power, $nbdays$ is the number of conference days, and CI is a carbon intensity of electricity generation.

We extended the above method to give more accurate estimates of the participation of the conference attendees and the carbon intensity of electricity generation. For a participant p we first estimate the total number of attendance hours $nbhours^p$ during the conference, and we search for the carbon intensity of electricity generation of the participant's country CI^p . Both values can be retrieved as explained in Section 4.1.2. If we can not find a CI^p for a participant's country, we use an aggregate value (i.e., global or per continent average).

We then perform the following estimations for a participant p

$$\begin{aligned} CO2_{net}^p &= nbhours^p \cdot bdwth \cdot kWh_{Gb} \cdot \left(\frac{CI_{ser} + CI^p}{2} \right) \\ CO2_{dev}^p &= nbhours^p \cdot devpwr \cdot CI^p \\ CO2^p &= CO2_{net}^p + CO2_{dev}^p \end{aligned} \quad (6)$$

⁵<https://app.electricitymaps.com/map>

where CI_{ser} is the carbon intensity of electricity generation where the server is hosted, and $bdwth$, kWh_{Gb} and $devpwr$ are the same as in Equation 5. Similar to the IEA method (see Section 4.1.2) we also set the carbon intensity of electricity generation as the average of the intensities of the participant’s country and the server’s hosting country.

Finally, for all participants p in a list of total participants \mathcal{P} , we estimate the total CO2 emissions of the conference.

$$\begin{aligned} CO2_{att} &= \sum_{p \in \mathcal{P}} CO2^p \\ CO2_{ser} &= nbdays \cdot nbhours \cdot serpwr \cdot CI^p \\ CO2_{total} &= CO2_{att} + CO2_{ser} \end{aligned} \tag{7}$$

4.2 Step 2: Building a community-guided discussion of the environmental effects of conferencing

This second step consists of presenting the emissions estimations obtained from the first step to the conference’s community in a conference session, opening a discussion with the community to raise the discussion about the ecological impacts of the conference, and collecting comments and feedback from the community. Collecting feedback from the conference’s community is essential since the emissions estimations can guide decisions regarding future editions of the conference, which directly impacts the conference community.

During the presentation, we collected two types of feedback: (1) verbal comments by the conference participants during the discussion session; and (2) written comments. We collect these written comments by offering the option to the participants to write anonymous comments on a collaborative pad. The pad can be organized into threads, where a participant starts a discussion topic, and others can react and comment on the topic. We foster the community’s reaction and potentially reduce any social pressure on the matter by letting participants post comments anonymously.

We afterward used the verbal and written comments to synthesize a discussion about the environmental effects of the conference. We decided on an approach of reacting to the comments directly, with the objective of merging our knowledge with the collective knowledge of the conference’s community. The output of this step is a tailored discussion guided by the conference’s community feedback.

5 Data and code availability

All data generated in this study have been provided in the Supplementary Information and deposited in GitHub [<https://github.com/danilo-carastan-santos/euro-par-travel-emissions>]. Python 3.9.12 was used to analyse data.

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Author contributions

The authors are listed by alphabetic order. Denis launched the idea of this study. All the authors participated to the discussions and elaboration of this work. Krzysztof and Leonel provided the access to the data. Danilo and Krzysztof contributed to the data processing, analysis, and results interpretation with the help of Denis. Danilo was the main writer, and Denis was the main reviewer of Sections 2 and 3. Finally, all authors reviewed the final manuscript.

Competing interests

Krzysztof Rządca also works at Google.