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Life Cycle Assessment of In-Person, Virtual, and Hybrid Academic Conferences: New Evidence and Perspectives

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This study contributes to the debate on the environmental impacts of academic conferences by comparing the life cycle impacts of a sample of real-world in-person, virtual, and hybrid conferences with different features and organizers. Results show that virtual formats reduce impacts by 2-3 orders of magnitude across all impact categories (for global warming, averagely from 941.9 to 1.0 kg CO2eq per person). The hybrid case study, with a share of 69% virtual attendees, displays an average 60% reduction in the indicator results, less than ideal cases where the farthest attendees join online. The cross-conference comparison allowed the identification of several drivers of impact variation. For in-person conferences, some never addressed drivers were uncovered, including the energy sources and systems used to supply the venue or the number of non-local staff members and exhibitors. For virtual conferences, the main impact driver is the average time spent online by delegates, surprisingly more related to virtual experience design than conference duration. The study further summarizes mitigation options from the literature and proposes new ones, such as selecting a venue supplied by a biomass-fueled district heating system or with a green electricity contract (around -41 and -1.9 kg CO2eq per person, respectively). Lastly, our work highlights the inconsistencies that affect current conference assessments and proposes new research avenues, advocating the need to shift the focus from optimizing single conferences to considering the optimal portfolio of conferences and other activities for academic societies to meet their members' needs while minimizing environmental impacts.

Keywords: Academic Conferences; Environmental Impacts; Life Cycle Assessment; Virtual Events; Hybrid Events; Carbon Footprint

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1. Introduction

Conferences represent a well-established practice in academia to facilitate the creation and dissemination of knowledge (Rowe 2018). They serve multiple important roles in the career of academics, enabling them – among others – to promote their work, attract feedback, and meet like-minded peers to build new research collaborations (Donlon 2021). These benefits, however, come with a significant drawback: conferences can be a high resource-demanding and emission-intensive process (Hischier and Hilty 2002). In the past two decades, scholars in different fields have started to disclose the greenhouse gas (GHG) emissions associated with conferences, especially conference travel, showing alarming figures (Jäckle 2019; Kuper 2019). For instance, Klöwer et al. (2020) found that the per capita footprint of scientists traveling to the 2019 Fall Meeting of the American Geophysical Union was about 3 tons of CO_{2eq}, greater than the amount many citizens around the world emit over an entire year.

Against this backdrop, a growing movement has started to question the established model of in-person conferencing and advocate the need, well before the Covid-19 pandemic, to leverage significant improvements in videoconferencing technologies to switch to more sustainable formats, such as virtual or hybrid conferences (Fraser et al. 2017; Reay 2003). A few pioneers have led the way – see Dolci et al. (2011) – but these were very isolated cases. The pandemic, however, upended the conference landscape and forced the switch to virtual formats to happen suddenly across all fields. Many regarded it as a great opportunity for academia to reinvent its conferencing model (Jordan and Palmer 2020). More recently, some conferences have also experimented with hybrid formats, where some attendees join in person and others virtually (Langin 2021). With the world progressively reopening, organizers are confronted with the task of designing the conferences of the future and are looking for evidence to make informed decisions.

From an environmental perspective, however, Tao et al. (2021, p.2) highlight that “there is a minimal quantitative understanding of the environmental impacts from different modes of conferences. To understand the sustainability implications of future conferences and inform the policies, it is essential to quantify the environmental footprints of virtual, in-person, and hybrid conferences”.

Previous studies have extensively analyzed the GHG emissions associated with travel to in-person conferences and ways to reduce them (Burtscher et al. 2020; Coroama et al. 2012; Desiere 2016; Fois et al. 2016; Jäckle 2019; Klöwer et al. 2020; Kuonen 2015; Kuper 2019; Orsi 2012; Ponette-González and Byrnes 2011; Spinellis and Louridas 2013; Stroud and Feeley 2015; van Ewijk and Hoekman 2021). Among these, a few studies also considered virtual and hybrid conferences, either treating them as carbon-neutral scenarios (Jäckle 2019; van Ewijk and Hoekman 2021) or assessing their footprint in a simplified way (Burtscher et al. 2020; Klöwer et al. 2020). Some studies adopted a broader scope and conducted comprehensive life cycle assessments (LCA) of in-person conferences’ impacts (Astudillo and AzariJafari 2018; Hischier and Hilty 2002; Neugebauer et al. 2020), considering activities other than delegate travel, such as accommodation, and impact categories other than climate change, such as human toxicity, thus providing richer insights to organizers. Among these, Hischier and Hilty (2002) also considered the virtual format, even if modelled through a conjectural scenario, whereas none assessed comprehensively the impacts of a hybrid conference. Two recent articles addressed this gap, both leveraging the data from a virtual conference of the Covid era and building in-person and hybrid counterfactuals through scenario analysis (Jäckle 2021; Tao et al. 2021).

None of the previous comprehensive LCA studies, however, considered multiple conferences with different features (e.g., size, location, audience), thus hampering the transferability of the results

and making it difficult to highlight potential drivers of impact variation across different conferences. Some non-LCA travel-focused studies considered multiple events (e.g., Jäckle 2019; van Ewijk and Hoekman 2021) – typically of the same academic society – but their limited scope prevented the identification of drivers of impact variations within processes other than travel and trade-offs between different impact categories. Regarding format comparison, then, the exclusive reliance on scenario analyses means that the actual choices of stakeholders in real-world settings remain unknown and the projected results need validation. Lastly, while some studies have identified a few issues affecting the validity of format comparisons, such as functional equivalence (Hischier and Hilty 2002) and ripple/rebound effects (Coroama et al. 2012; Takahashi et al. 2006), to the best of our knowledge, none has comprehensively and critically investigated the inconsistencies related to current conference assessments/comparisons, which may have led to an overemphasis of some issues and the neglection of others.
To address these gaps and move the debate forward, the goals of this study are to (1) quantify and compare the overall environmental impacts of real-world in-person, virtual, and hybrid conferences; (2) identify potential drivers of impact variation across conferences with a different size, location, duration, organizer, and audience; and (3) investigate the inconsistencies that can affect the validity of conference assessment results. Additionally, a summary of the main mitigation options proposed in previous literature and an investigation of some never-considered ones are also included in the scope of the study. To this end, we leverage comprehensive LCA data gathered from a sample of conferences organized by three academic societies in the field of Operations Management and Operations Research (OM&OR): the US-based *Institute for Operations Research and the Management Sciences* (INFORMS) and *Production and Operations Management Society* (POMS), and the Europe-based *European Operations Management Association* (EurOMA).

2. Methods

The LCA method in compliance with ISO 14044 standard was implemented, including its four phases: goal and scope definition, life cycle inventory analysis (LCI), life cycle impact assessment (LCIA), and interpretation of the results (ISO 2017).

2.1 Goal and scope definition

To achieve the goals stated above, we selected a convenience sample of conferences held in different formats (in-person, virtual, and hybrid) and with different features (organizer/audience, size, location, duration, period). Particularly, given the high data and resource requirements of LCA, we targeted the most recent annual meetings organized in each available format by the supporting societies, which guaranteed both the availability of accurate data and the desired heterogeneity (see Table 1). Following Tao et al. (2021), the functional unit was defined as "one average conference participant", for a fair comparison across different conferences and formats.

2.1.1 System boundary

To define the system boundary, we started from the LCA model provided by Cavallin Toscani et al. (2022) applicable to generic in-person events and adapted it to academic conferences by looking at the studies by Hischier and Hilty (2002) and Neugebauer et al. (2020). For virtual and hybrid formats, we further integrated input from Tao et al. (2021). Figure 1 shows the resulting life cycle representation. On the left side, there are the background processes that provide energy, material, and product inputs to conference activities or dispose of their waste outputs. To model them, we relied extensively on internationally recognized LCI databases (see next section). On the right are the foreground processes that cluster the impactful activities associated with conference organization and delivery. To model them, we mostly relied on primary data provided by conference organizers or secondary data retrieved from literature (see Section 2.2).

Conference	Format	Period	Duration[a]	Attendees	Venue
INFORMS 2019	In-person	October 2019	4+1 days	7,072	Seattle (US): Washington State Convention Center + Sheraton Grand Seattle.
INFORMS 2020	Virtual	November 2020	6+1 days	5,501	Online: in-house virtual platform + Zoom.
INFORMS 2021	Hybrid	October 2021	4+1 days	6,109 (1,921 in-person)	Anaheim (US): Anaheim Convention Center + Anaheim Marriott. Online: in-house virtual platform + Zoom.
POMS 2019	In-person	May 2019	4+1 days	2,000	Washington DC (US): Washington Hilton.
POMS 2021	Virtual	April-May 2021	5+1 days	1,488	Online: in-house virtual platform + Zoom.
EurOMA 2019	In-person	June 2019	3+2 days	561	Helsinki (FI): Hanken School of Economics + Aalto University Business School.
EurOMA 2021	Virtual	July 2021	3+1 days	340	Online: Exordo virtual platform.

[a] Additional days include pre-conference events such as doctoral seminars, business meetings of academic journals/societies, special interest groups, etc.

Table 1 – Conferences under study

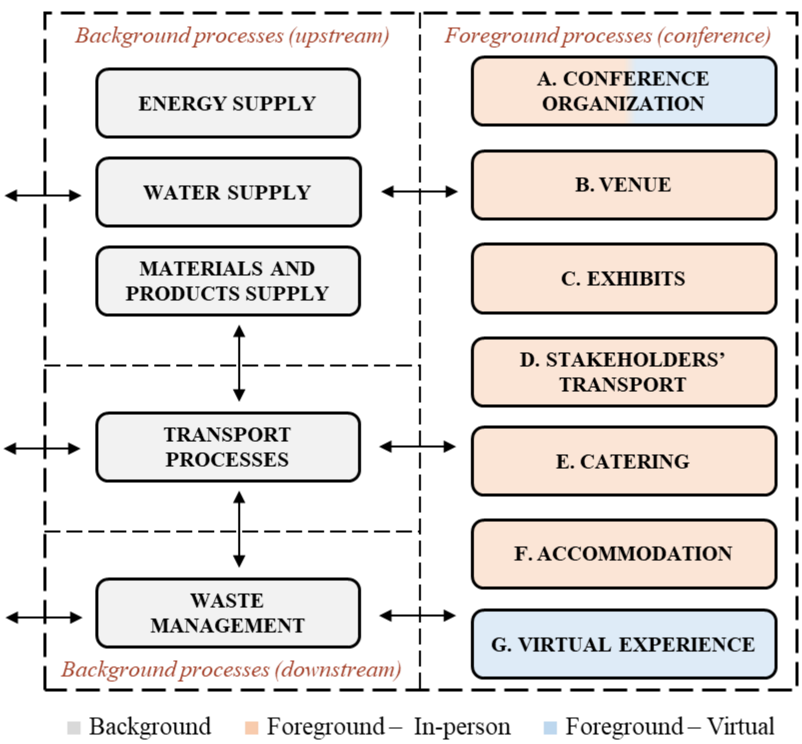

Figure 1 – LCA model for academic conferences

Regarding the foreground processes that characterize in-person conferences, *Conference organization* refers to general planning activities, such as conference-related board meetings, venue inspection visits, organizing committee's and secretariat's activities, track and session chairs' activities, pre-conference participants' activities, and conference materials – including their production, shipping, and disposal. *Venue* refers to the conference-related use of the venue and buildings, mostly including the energy consumption of conference rooms and equipment. *Exhibits* includes the production, transportation, and disposal of exhibition and/or career fair materials, where applicable[1]. *Stakeholders' transport* refers to the transportation of attendees, exhibitors, and staff to reach the conference site, and, where applicable, for industry visits. *Catering* includes the production and transportation of food and beverage items consumed at the conference. Lastly, *Accommodation* refers to overnight stays of conference stakeholders.

For virtual conferences, *Conference organization* has the same meaning as before, even though in this context most activities are virtualized and dematerialized. *Virtual experience* refers to the use of electronic and internet devices to connect event participants during and after the event, including the direct energy use and the indirect energy and materials used for device production. Hybrid conferences are, environmentally speaking, simply a concatenation of previous formats. Additional equipment is required to live stream presentations from the venue (Coroama et al. 2012), but in our model, this extra consumption is absorbed by the *Venue* process.

Decisions on not including some activities/flows in the system boundary were based on one or more of three exclusion criteria: lack of relevance to the overall results, lack of accurate primary and secondary data, and not clear allocation of responsibility to the conference. The last criterion, particularly, explains why we did not include the home consumption of food and energy for virtual conferences, and the extra-conference consumption of food or other commodities for in-person. Differently from Tao et al. (2021), indeed, we opted here for a "control" approach (Cavallin Toscani et al. 2022), where only activities under the control of conference organizers are considered, as further discussed in Section 3.3. Other items excluded according to the above criteria encompass: computer usage for abstract and/or full paper drafting, composite gadgets distributed to attendees (e.g., safety kits), venue water and other material consumption (e.g., cleaning products), travel of stakeholders in their country to reach the airport/station of departure and within the conference location for extra-event activities, and fuel and water use for food preparation.

2.1.2 LCI databases and LCIA methods

The *SimaPro* software and authoritative LCI databases therein implemented were employed to perform the analyses. Particularly, we made extensive use of the *ecoinvent 3.8* database (Wernet et al. 2016) as our primary source of LCI data for background processes. When available, data with geographical coverage related to the country/region where the conference took place were selected, otherwise, globally averaged data were used. In rare cases in which the needed process data were not available – especially for food production – we further relied on *Agri-footprint 5.0* (Paassen et al. 2019) database.

For the LCIA, following Tao et al. (2021), the well-established ReCiPe 2016 method was chosen, with the hierarchist perspective (Huijbregts et al. 2017). It incorporates a comprehensive set of impact categories, namely Global warming (GW), Stratospheric ozone depletion (SOD), Ionizing

[1] Some academic conferences comprise exhibition spaces where organizations can promote their products/services. Some conferences, especially in the US, also involve career fairs that serve the purpose of matching recruiters and job seekers (mostly academic institutions).

radiation (IO), Ozone formation-Human health (OF-HH), Fine particulate matter formation (FPMF), Ozone formation-Terrestrial ecosystems (OF-TE), Terrestrial acidification (TA), Freshwater eutrophication (FEu), Marine eutrophication (MEu), Terrestrial ecotoxicity (TEc), Freshwater ecotoxicity (FEc), Marine ecotoxicity (MEc), Human carcinogenic toxicity (HCT), Human non-carcinogenic toxicity (HnCT), Land use (LU), Mineral resource scarcity (MRS), Fossil resource scarcity (FRS), and Water consumption (WC).

2.2 Life cycle inventory

For each conference, data were collected and/or calculated for all the foreground processes in Figure 1. The main data sources were the conference organizers and/or society leaders, who gave us access to conference-related documents (e.g., conference schedule, proceedings, list of participants, etc.) and answered our questions in ad-hoc interviews. Despite this, many assumptions had to be made to make provided information usable in an LCA setting or to fill data gaps. We strived to remain consistent and when there were some gaps for a conference, missing data were either extrapolated from other conferences or derived from authoritative secondary sources. As prescribed by ISO 14044, all assumptions and collection/calculation procedures were documented in ad-hoc built data collection sheets to increase the transparency and replicability of the study. Particularly, for all conferences, we created a spreadsheet that details the list of modeled activities and related sub-activities/materials. Furthermore, for all sub-activities, it specifies: the name of the linked ecoinvent dataset containing relevant background data, the measured/calculated value of the flow[2], the associated unit of measure, and all relevant information and assumptions regarding data collection/calculation. These files are available from the authors upon request. In the Appendix, instead, the general logic and main assumptions that were used to calculate the inventory of each unit process are described.

3. Results and Discussion

3.1 Life cycle impact assessment results

Regarding the impact quantification and comparison across formats, Table 2 reports the LCIA results for the analyzed conferences. The first row related to the GW category shows the per capita carbon footprints, with an average of 941.9 kg CO_{2eq} for in-person conferences and 1.0 kg for virtual – almost three orders of magnitude of difference. The last instead related to the WC category displays the water footprints, with an average of 2602.7 l for in-person and 9.0 l for virtual – more than 2 orders of difference. For other impact categories as well, the difference between in-person and virtual is mainly between 2 and 3 orders of magnitude. To understand the scale of such difference, the carbon footprint of an average in-person attendee alone is about twice the total footprint of EurOMA 2021 (488.3 kg CO_{2eq}).

Figures 2 and 3 display for each in-person and virtual conference, respectively, the contributions of all conference stages to the single impact categories, normalized against the indicator results of the conference with maximum impact. For in-person conferences, in line with Neugebauer et al. (2020), *Stakeholders' transport* dominates most impact categories, with particularly large shares in those driven by fossil fuel consumption, such as GW (~93% averagely), OF-HH/TE (~97.6%),

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[2] To facilitate understanding, values in the collection sheets refer to the entire conferences and not to the functional unit of an average conference participant. To move from total to in-person figures, the values need simply to be divided by the number of attendees.

and FRS (~93%). *Accommodation* instead is the primary contributor to MEu (~63.9%) and WC (~56.8%), with significant shares also for FEc and MEc, driven by the material and energy consumption of hotel operations. The *Venue* process has an average share of 2.5% across all categories and conferences, with a maximum of 9.5% for IR, due to the consumption of electricity produced from nuclear power in some conference locations (e.g., Finland for EurOMA 2019). The food production for *Catering* is responsible for the large share in the LU category (37%), and the shares of 18.8% and 12.1% in the WC and MEu categories. The latter two are also significantly driven by *Conference organization*, with contributions of 8.1% and 9% respectively, mostly due to the production of conference materials. Lastly, *Exhibits* have a neglectable impact across all categories (average of 0.05%).

Impact category	Unit	In-person			Virtual			Hybrid	
		INFORMS 2019	POMS 2019	EurOMA 2019	INFORMS 2020	POMS 2021	EurOMA 2021	INFORMS 2021	Only in-person[a]
GW	kg $CO_{2\,eq}$	9.87E+02	1.07E+03	7.65E+02	7.15E-01	9.87E-01	1.44E+00	4.01E+02	1.28E+03
SOD	kg $CFC11_{eq}$	2.78E-04	3.20E-04	2.52E-04	3.17E-07	4.26E-07	6.15E-07	1.16E-04	3.70E-04
IR	kBq Co-60_{eq}	1.20E+01	1.37E+01	1.13E+01	6.91E-02	1.13E-01	1.67E-01	4.74E+00	1.51E+01
OF-HH	kg $NO_{x\,eq}$	4.72E+00	4.95E+00	3.45E+00	1.98E-03	2.31E-03	3.34E-03	1.84E+00	5.85E+00
FPMF	kg $PM2.5_{eq}$	1.02E+00	1.08E+00	7.72E-01	1.53E-03	2.22E-03	3.22E-03	4.01E-01	1.27E+00
OF-TE	kg $NO_{x\,eq}$	4.76E+00	5.00E+00	3.48E+00	2.01E-03	2.34E-03	3.38E-03	1.86E+00	5.91E+00
TA	kg $SO_{2\,eq}$	2.94E+00	3.11E+00	2.24E+00	2.85E-03	3.75E-03	5.40E-03	1.16E+00	3.69E+00
FEu	kg P_{eq}	2.04E-01	2.17E-01	1.71E-01	4.37E-04	6.53E-04	9.23E-04	7.88E-02	2.51E-01
MEu	kg N_{eq}	2.24E-02	2.58E-02	2.61E-02	5.07E-05	8.03E-05	1.09E-04	8.53E-03	2.71E-02
TEc	kg 1,4-DCB	1.83E+03	1.97E+03	1.41E+03	4.63E+00	4.33E+00	5.87E+00	7.49E+02	2.38E+03
FEc	kg 1,4-DCB	7.90E+00	9.94E+00	7.41E+00	1.20E-01	1.62E-01	2.18E-01	3.75E+00	1.19E+01
MEc	kg 1,4-DCB	1.14E+01	1.41E+01	1.05E+01	1.55E-01	2.10E-01	2.83E-01	5.33E+00	1.69E+01
HCT	kg 1,4-DCB	9.19E+00	1.17E+01	7.89E+00	3.96E-02	6.00E-02	8.47E-02	4.34E+00	1.38E+01
HnCT	kg 1,4-DCB	3.28E+02	3.77E+02	2.51E+02	1.86E+00	2.48E+00	3.34E+00	1.41E+02	4.48E+02
LU	m2a $crop_{eq}$	2.19E+01	2.82E+01	3.94E+01	1.61E-02	2.10E-02	2.99E-02	9.34E+00	2.97E+01
MRS	kg Cu_{eq}	5.24E-01	6.76E-01	4.62E-01	6.20E-03	7.99E-03	1.05E-02	2.56E-01	8.15E-01
FRS	kg oil_{eq}	3.14E+02	3.43E+02	2.42E+02	1.88E-01	2.47E-01	3.60E-01	1.28E+02	4.08E+02
WC	m3	2.46E+00	2.73E+00	2.63E+00	5.64E-03	8.84E-03	1.27E-02	9.34E-01	2.97E+00

[a] Indicator results for INFORMS 2021 in-person attendees only

Table 2 – LCIA results

Virtual conferences, instead, have a more stable pattern across categories, with *Virtual experience* responsible for greater impact shares than *Conference organization* – 59.2% versus 40.8% on average – both driven by the energy consumption of electronic devices and the material consumption for their production.

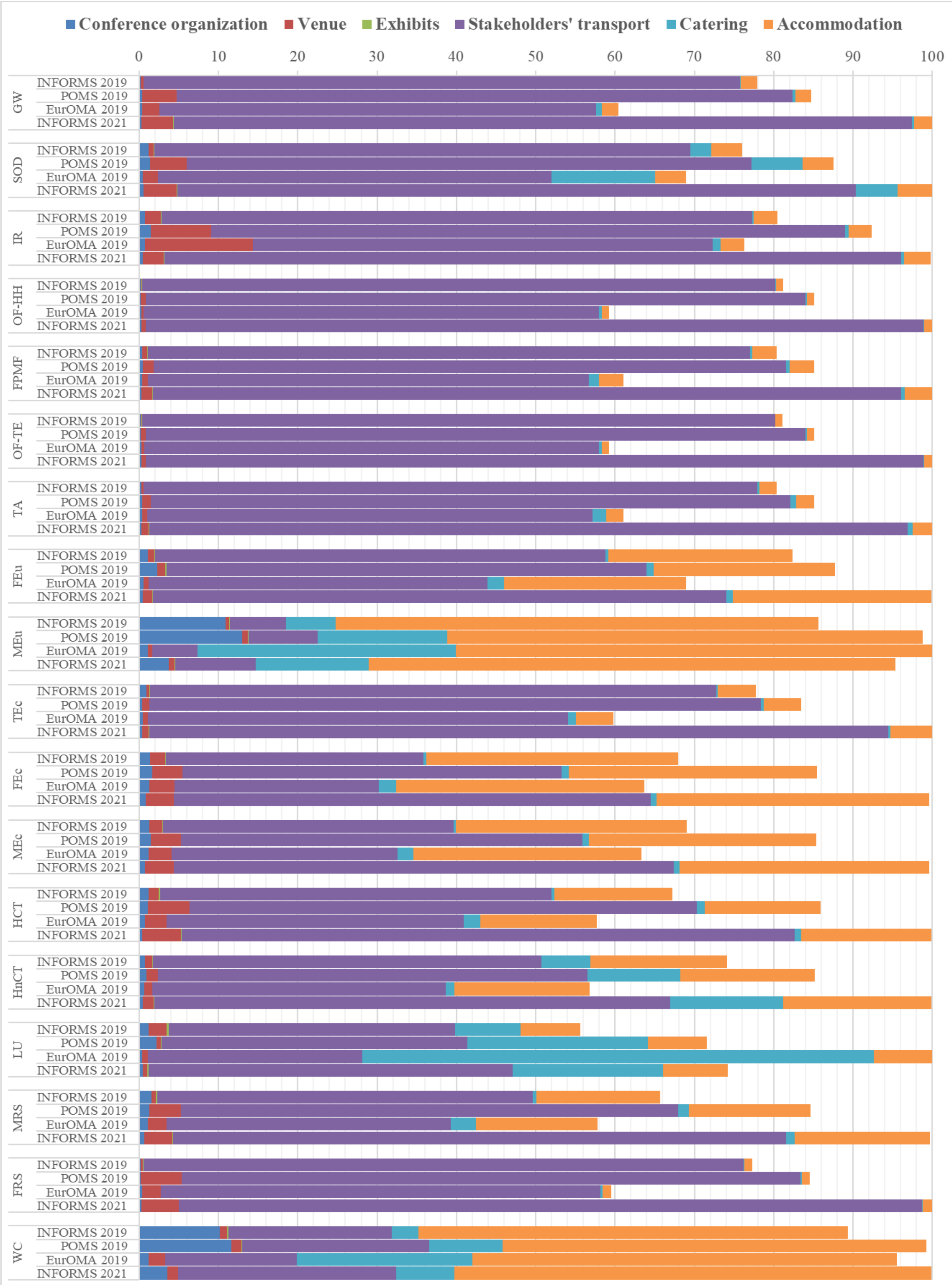

Figure 2 – Impact breakdown by conference stage for in-person conferences

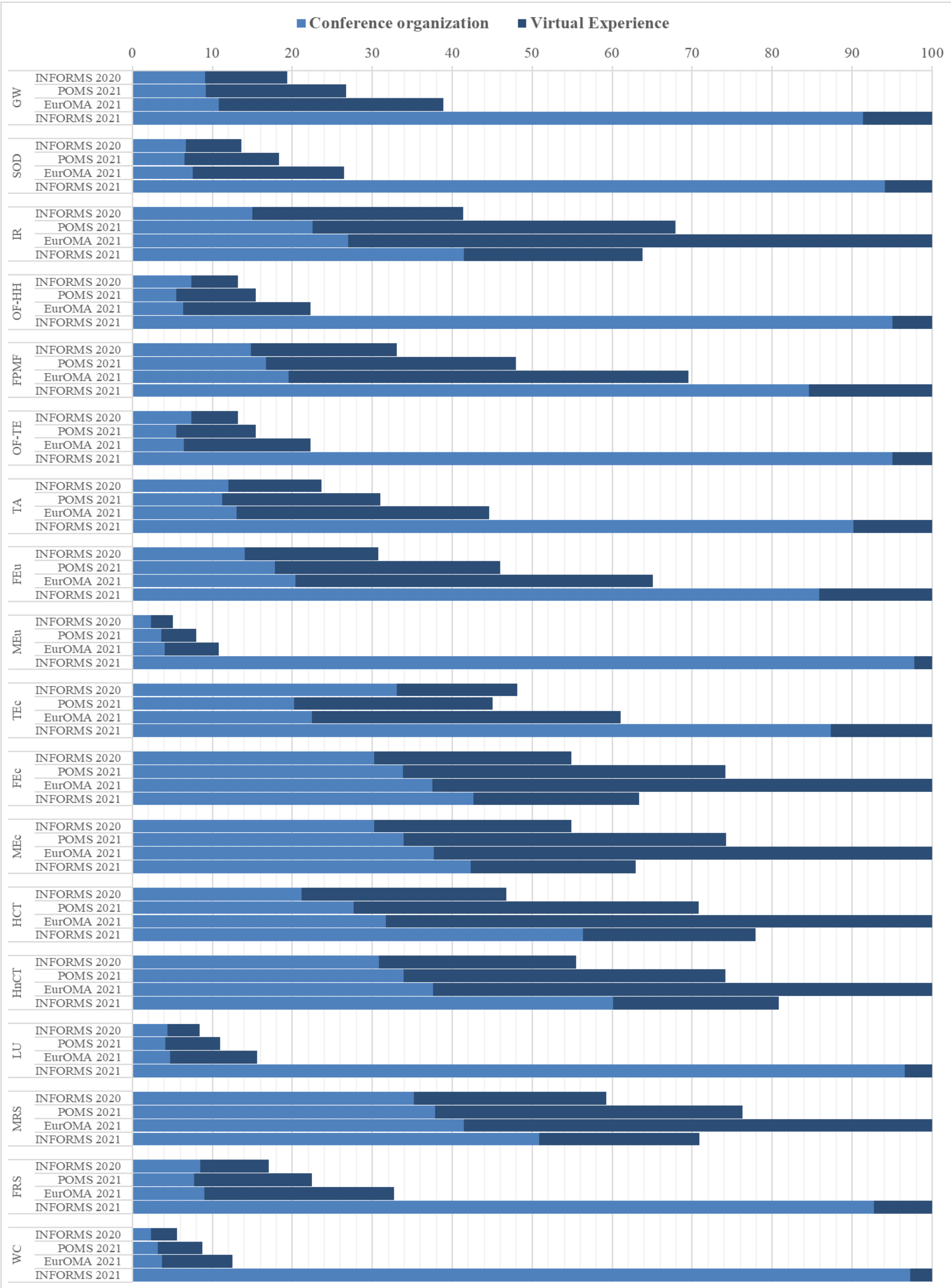

Figure 3 – Impact breakdown by conference stage for virtual conferences

Focusing on INFORMS 2021 – the first hybrid conference ever assessed – the impact breakdown is reported for both in-person (Figure 2) and virtual (Figure 3) attendees. For the formers, the impact profile looks equivalent to that of an in-person event. Impacts are larger than in other conferences for reasons that are explained in the next section. For virtual attendees, instead, the impact profile looks quite different from other virtual conferences. That occurs because the *Conference organization* stage includes the planning activities for the whole event, including those for the in-person component that are more energy and material demanding. The *Virtual Experience* stage is instead similar to that of INFORMS 2020. What is not captured in previous graphs is the overall benefit of a hybrid event (see Table 2). Compared to INFORMS 2019, an average 60% reduction is obtained in the overall per-capita indicator result. This is around 20% less than what was projected by Tao et al.' simulation (2021) with the same share of virtual attendees, i.e., 68.6%. Indeed, they considered an ideal scenario in which the farthest attendees join online. In real cases, that can hardly be enforced by organizers without incurring discriminatory behavior. However, they might design ad-hoc incentives and promotion campaigns to attract a larger share of virtual attendees and prompt faraway delegates to attend online.

3.2 Drivers of impact variation

Regarding potential drivers of impact variation, our identification strategy was primarily based on spotting significant differences across the impact profiles of conferences within the same format and working backward to find the reasons behind them.

For in-person conferences, a large variation can be seen in the impacts of *Stakeholders' transport*, with INFORMS and POMS attendees displaying greater travel impacts than EurOMA ones. As expected, this is mainly related to the average travelled distances, with POMS and INFORMS attendees traveling greater distances than EurOMA ones (see Table 3 for a summary of travel metrics). EurOMA has indeed a more concentrated audience – typical of European conferences (Desiere 2016) – with a prevalence of medium-haul travelers from Europe. The American conferences, instead, have a larger share of long-haul travelers, mostly coast-to-coast travelers in the US and inter-continental travelers. POMS 2019, particularly, has a larger share of non-US attendees, which explains its greater average distance than INFORMS 2019. This does apply to INFORMS 2021, probably due to its location in Los Angeles which allowed for better flight connections.

The greater distances traveled by INFORMS 2021 attendees, however, seem not to explain alone their much larger transportation footprint. We discovered an extra impact associated with the transportation of staff and exhibitors. EurOMA and POMS represent typical small/middle-size societies with contained organizational structures. In their conferences, mostly local student volunteers are hired as staff and exhibitors encompass only a few publishers and companies. INFORMS is instead a more structured organization that combines local staff with full-time staff traveling from event to event. Its conferences further involve a large exhibition space with dedicated personnel from many companies and recruiting institutions. The allocation of staff and exhibitors' travel to attendees explains the impact surplus. The same applies also to *Accommodation* impacts, which are greater for INFORMS conferences *ceteris paribus*. The effect is proportional to the ratio between the number of non-local workers and the number of attendees: 1 every 100-200 at EurOMA and POMS, 1 every 50 at INFORMS 2019, and 1 every 10 attendees at INFORMS 2021. Interestingly, the total number of staff members at INFORMS 2021 was greater than in 2019 (222 versus 150), against a number of in-person attendees that was less than one-third. This may be attributable to several reasons (e.g., greater complexity of running a hybrid event, unexpected reductions in the number of in-person attendees), which need further investigation.

	Conference	Type of Transport					
		Landbound[a]	**Air - Very Short Haul**	**Air - Short Haul**	**Air - Medium Haul**	**Air - Long Haul**	**Total or Average**
Share of Travelers [%]	INFORMS 2019	7.6	0.1	2.7	39.1	50.5	100
	INFORMS 2021	5.9	3.3	1.4	39.1	50.3	100
	POMS 2019	15.8	16.8	11.6	13.9	42.0	100
	EurOMA 2019	7.5	8.6	10.9	52.8	20.3	100
Average Traveled Distance [km]	INFORMS 2019	163.46	1403.50	2365.56	5860.49	13757.71	9324.64
	INFORMS 2021	167.18	1227.28	2293.03	5954.92	15534.27	10228.20
	POMS 2019	619.63	1322.32	2139.62	4842.56	19676.19	9502.63
	EurOMA 2019	40.00	897.44	2305.67	4547.03	20160.58	6826.43
Share of Transport GHG Emissions [%]	INFORMS 2019	1.3	0.0	0.8	24.6	73.2	100
	INFORMS 2021	3.5	0.6	0.4	22.3	73.3	100
	POMS 2019	3.8	3.6	3.1	6.9	82.6	100
	EurOMA 2019	1.2	1.8	4.4	35.0	57.7	100

[a] *Share of Travelers* and *Average Traveled Distance* do not include the airport-venue connection for air travelers, while *Share of Transport GHG Emissions* does

Table 3 – Travel patterns by type of transport within in-person conferences

Another significant difference regards *Venue* impacts, which are much lower across all categories for INFORMS 2019: for GW, 2.9 kg CO_{2eq} per person versus 56 kg of POMS 2019. This is due to the different energy source and supply system used to produce the heat consumed at the venue. For INFORMS 2019, indeed, a district heating system fueled by wood waste was used to supply conference buildings, less impactful than the traditional gas boilers employed in other venues. Other potential drivers for *Venue* impacts are the period and location in which the conference is held, which we did not capture because of the use of yearly and geographically averaged data. Spring and fall conferences are likely less energy demanding than winter and summer ones, depending on the location.

Another variation can be noticed in the impacts of *Catering*, which are larger across all categories for EurOMA 2019, a surprising result since its organizers purposefully offered a vegetarian-only menu in most meals. This can be explained by the consolidated practice in European conferences of covering most meals within registration fees, as opposed to most American ones where only a few receptions and luncheons are offered – 4 meals per registrant at EurOMA versus 1.5 at POMS and 0.5 at INFORMS. Integrating the food consumed by participants outside the conference – often fast food – or normalizing the figures against the number of offered meals would reverse this result (Neugebauer et al. 2020). Lastly, a minor difference regards, again for EurOMA, the lower impact of *Conference organization* in those categories driven by resource consumption (e.g., LU and WC), reflecting the effort of its organizers to reduce conference materials as much as possible. It is worth noting that some previous considerations are valid because the analyzed conferences had almost the same duration – 3-4 days, typical in the OM&OR field. Duration could indeed represent an important driver of variation, as some stages like *Venue*, *Catering*, and *Accommodation* are dependent on it. An increase in the conference days would increase both the relative impact shares of previous stages and the overall absolute values. Another potential driver

not captured above is the accommodation type used by attendees. We had granular data only for INFORMS conferences in terms of the percentage of stakeholders staying in 4-stars and 3-stars hotels and extrapolated them to EurOMA and POMS, thus not capturing their actual patterns and neglecting other less used accommodation types (e.g., luxury hotels, hostels, rented flats, etc.). Figure A1 in the Appendix shows the LCIA indicator results per *guest·night* for different accommodation options modeled in ecoinvent, highlighting the large difference that can arise.
As to virtual conferences, a large variation is visible going from INFORMS 2020 to POMS 2021 and then EurOMA 2021, with the impact contributions of *Virtual experience* and, consequently, the overall indicator results increasing. By analyzing platform analytics data, we found the reason for this in the different amount of online activity of attendees, with EurOMA attendees being connected in total for ~8.9 h per person and INFORMS ones for ~2.8 h (no granular data for POMS). Surprisingly, this is unrelated to the conference duration: EurOMA lasted half as long as INFORMS (3 days versus 6) but its attendees stayed connected for around three times as long. It has probably more to do with how the virtual experience was designed. EurOMA chose a synchronous format with all live streamed presentations, while INFORMS, due to its larger size and related planning difficulties, opted for an asynchronous format with mostly pre-recorded presentations. This different engagement level should be considered by organizers when planning future virtual conferences. Another driver suggested by Tao et al. (2021) is the geographical distribution of attendees, which can affect the upstream production of energy used in electronic devices (*Virtual experience* stage) and which we did not capture because of the use of globally averaged data.
Table 4 sums up the main variation drivers identified in the analysis.

Format	Driver	Affected stages
In-person	Average distance travelled by attendees → Membership distribution vs conference location	Stakeholders' transport
	Number and origins of staff, exhibitors, recruiters → society size and value proposition	Venue, Exhibits, Stakeholders' transport, Accommodation
	Energy source and supply system → conference location and venue	Venue
	Conference period vs conference location	Venue
	Number and types of meals	Catering
	Number and types of conference materials	Conference organization
	Conference duration	Venue, Catering, Accommodation
	Accommodation types used	Accommodation
Virtual	Time spent online by attendees → virtual experience design and conference duration	Virtual Experience
	Membership distribution	Virtual Experience
Hybrid (in addition to the above)	Share of virtual participation	All
	Extra number of staff members	Stakeholders' transport, Accommodation

Table 4 – Main drivers of impact variation for academic conferences

3.3 Mitigation options and scenario analysis

Apart from shifting to virtual and hybrid formats, previous studies have suggested several mitigation options to make in-person conferences greener. Most have righteously focused on air travel, being the predominant contributor to environmental impacts – see van Ewijk and Hoekman (2021) for a comprehensive overview. These include the shift to landbound transport for closer air travelers (Desiere 2016; Neugebauer et al. 2020), the optimization of the conference location based on attendees' origins (Jäckle 2019; Kuonen 2015), and the implementation of a multi-hub conference with inter-connected hubs in different locations and attendees traveling to the closest hub (Coroama et al. 2012; Klöwer et al. 2020) – see Parncutt et al. (2021) and Tao et al. (2021) for the issue of hub selection. These options can be theoretically very effective (GHG reductions going from 1% to over 80%), but practically quite difficult to implement for organizers, as proved by their almost null adoption.

Besides travel mitigation, some LCA studies have also assessed some easier options for organizers, such as reducing conference materials or making all meals vegetarian (Hischier and Hilty 2002; Neugebauer et al. 2020). These measures, though, produce a limited environmental benefit (less than 1% GHG reduction), as our data confirm. Improvements addressing *Accommodation* impacts could potentially be more effective, being the second most impactful stage. Neugebauer et al. (2020), for instance, suggested organizers could commit to partnering with hotels with green credentials, but the associated benefit remains uncertain due to the lack of proper LCI data. Relatedly, Figure A1 shows how impacts can change based on the chosen mix of accommodation types. Organizers could incentivize attendees to select the less impactful ones.

Regarding instead *Venue* impacts, our study suggests some novel mitigation options never addressed in previous literature. First, we have shown, through the INFORMS 2019 case, the substantial benefit of choosing a venue supplied by a biomass-fueled district heating system: 91.4% reduction in the *Venue* per-capita carbon footprint compared to other in-person conferences (-41 kg CO_{2eq}). We assess now, through scenario analysis, another option, namely the selection of a venue with a green energy contract that purchases electricity only from renewable sources. Since all systems should be optimized if we are to achieve carbon neutrality, we further introduce a mitigation option for virtual conferences, assessing a scenario where 50% of attendees have a green energy contract for their household – that could be rewarded by organizers through ad-hoc incentives. The scenario analysis was made possible by some recent datasets introduced in ecoinvent. Results are displayed in Figure 4.

The in-person scenario (4.a) leads to an average reduction of 0.8% across all categories and conferences. The absolute reduction in the carbon footprint is around 1.9 kg CO_{2eq} per person. The virtual scenario instead (4.b) drives an average reduction of 3.9%, which is greater for EurOMA as the time use of electronic devices was greater. For GW, this means an average reduction of 80 g CO_{2eq} per person. Interestingly, the use of green electricity in both scenarios leads to an increase in the water footprint (+2.1% for in-person, +11.8% for virtual), showing the trade-offs inherent in many technology shifts.

3.4 Inconsistencies in conference assessments and future developments

Our results confirm and extend the knowledge on the environmental impacts of conference formats, main impact drivers, and possible mitigation options, thus providing an updated and comprehensive picture to organizers and society leaders aiming to reduce the impacts of their conferences. In this section, however, we underline several issues that decision-makers and future evaluators should consider when interpreting the results from this and previous studies, and, accordingly, we propose some avenues for future research.

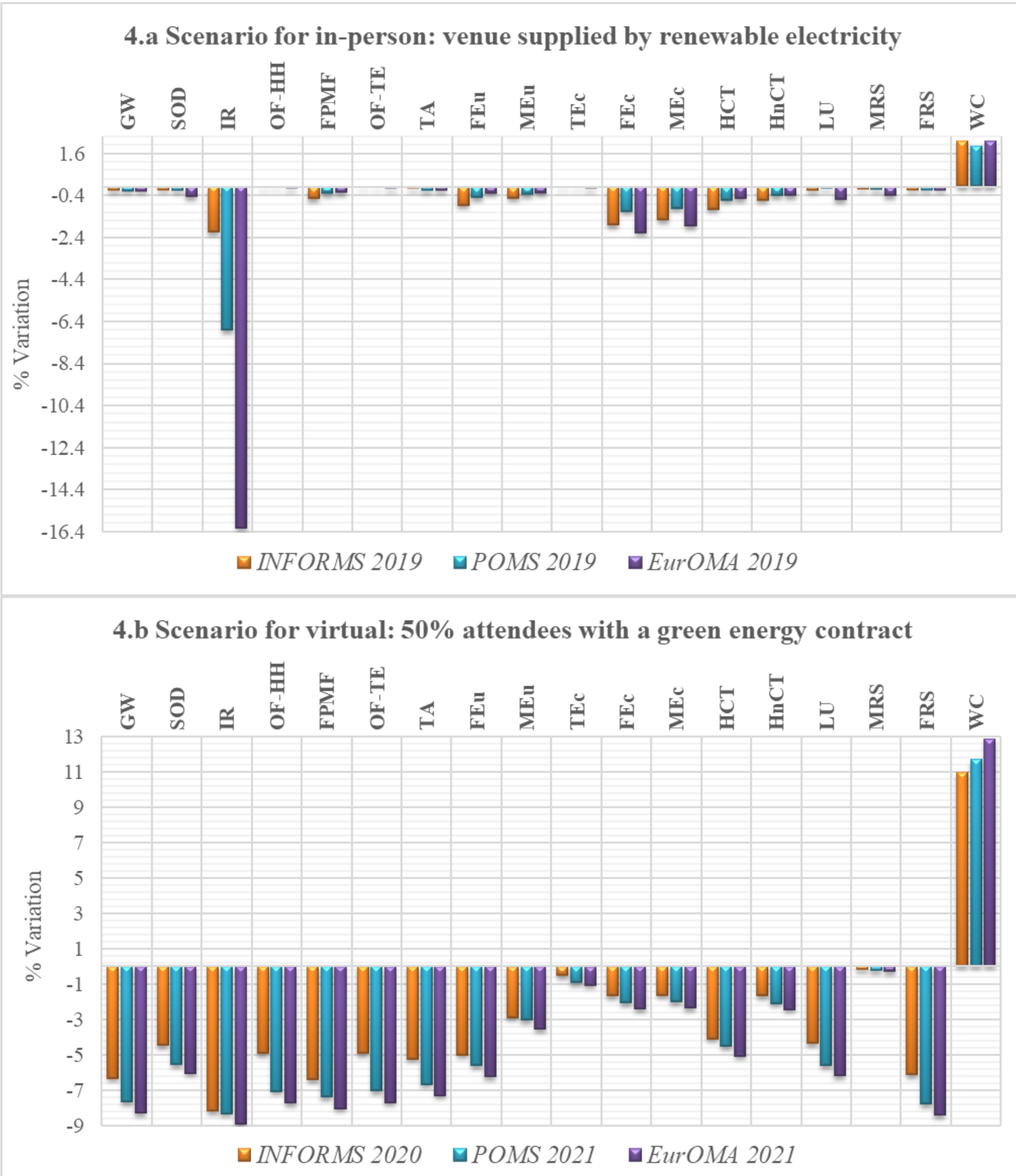

Figure 4 – Scenario analysis results: (4.a) scenario for in-person, (4.b) scenario for virtual

The first group of issues regards *system boundary and allocation*. Several underlying assumptions are made in setting the scope of conference assessments that can heavily affect their results. Starting from transportation, all studies allocate the entire travel impact to the conference itself. However, it is not uncommon for many attendees – especially distant ones – to combine the conference visit with other activities that would otherwise require separate trips, such as project meetings or family holidays. In these cases, only a share of travel impacts should be allocated to the conference, which may drastically reduce the impacts. Another issue regards food and other commodities consumption. In this and other studies (e.g., Neugebauer et al. 2020), we included only the food consumed at the venue, which is under the control of the organizer. Tao et al. (2021) instead considered the overall food consumption during the conference days, inside and outside the conference. For virtual conferences as well, they included the home consumption of food and energy, obtaining much larger impacts than this study. What should be allocated to conference responsibility is questionable and both approaches have their legitimacy. A strategy that could turn useful in both cases is to consider the *additionality principle* and compare the selected consumption activities to a business-as-usual scenario – i.e., what would have occurred if the conference had not taken place. For instance, Collins and Cooper (2017) calculated the "net" ecological footprint of a festival attendee by subtracting the footprint at home from the footprint at the festival.

The second group of issues regards *format comparison*, with the main one being *format inequivalence*. According to LCA standards, "comparisons between systems shall be made on the basis of the same function(s)" (ISO 2017, p.8). However, when considering different conference formats, it has long been clear that videoconferencing solutions do not perform the same functions as in-person meetings (Hischier and Hilty 2002; Takahashi et al. 2006). A survey we ran with the members of supporting societies found that virtual conferences are not able to provide the same networking and socialization opportunities as in-person, even if they provide other functions, such as greater flexibility and accessibility for underrepresented groups. For a fairer comparison, and more conscious choice of how to organize upcoming conferences, future research should try to assess the social impacts and scientific added-value of different formats and combine them with environmental results by means of more holistic techniques, such as *multiple-criteria decision analysis* or *cost-benefit analysis* (see for example Andersson and Lundberg, 2013). Another relevant issue regards then *ripple* or *rebound effects* in format shifts (Coroama et al. 2013). Takahashi et al. (2006, p.288) stated that virtual options "sometimes change our lifestyle and such changes can induce new environmental loads". For example, the lower costs of virtual conferences could induce more academics to attend[3] or more conferences to be organized per year, or the saved money and time could be spent on other impactful activities, thus increasing the overall environmental burden. Considering these effects would require an expansion of the system boundary and the design of proper allocation rules. An alternative would be to move from attributional LCAs to *consequential LCAs* studying the effect of several stakeholders' decisions (Palazzo et al. 2020).

All these considerations, however, made us think about the very framing of the problem and the necessity to go back to the basics. Academics do not need conferences *per se*, they need to network, promote their research, attract feedback, etc., and conferences are just a way to meet these needs aggregately. They bundle a series of services together, such as technical sessions, award ceremonies, and social gatherings, that meet different needs and that could also be provided individually or in different combinations (e.g., seminar series, PhD summer schools). Therefore, the functional unit should not be the organization of a conference, but the delivery of a set of services to meet members' needs along a given time frame. Furthermore, each bundle of services can be provided in in-person and virtual formats, and arguably in-person formats meet some needs better and virtual others. Thereby, in-person and virtual formats should be treated as complements

[3] This was not the case in our conferences, probably for the high prices set for virtual formats. Virtual conferences from other fields showed instead a great increase in attendance thanks to their better accessibility (Skiles et al. 2022).

and not as alternatives. The major question for an academic society should then be what the real needs of its members are and what the optimal number, type, and format of activities is to meet them while minimizing environmental impacts. In the end, the sustainability idea is about meeting the needs of stakeholders while remaining within ecological boundaries. This could be done also at the individual level, considering the portfolio of activities to meet the needs of a single academic – Achten et al. (2013) did something of the kind for PhD students. We believe this shift towards a portfolio approach considering the real needs of academics holds promise to move the debate forward and provide academic societies and institutions with the required input to revise their whole business model in a more sustainable way.

4. Conclusion

This study compared the life cycle impacts of seven real-world in-person, virtual, and hybrid conferences organized by different societies and with different features. The organizing societies belong all to the OM&OR field, which together with the reduced number of cases, may limit the generalizability of the results. Still, our sample presents greater size and heterogeneity than all previous comprehensive LCA studies, which allowed us to uncover significant drivers of impact variation (Table 4). In addition to expected ones, such as the average distance travelled by delegates, new ones were spotted. For in-person conferences, the number of non-local staff members and exhibitors – dependent on society's size and value proposition (e.g., provision of a career fair) – plays an important role in transportation and accommodation impacts. The energy sources and systems used to supply conference buildings instead greatly affect venue impacts. For virtual conferences, the main driver is the time spent online by attendees. Interestingly, instead of a direct consequence of conference duration, this seems to have more to do with how the virtual experience is designed, with synchronous modes leading to greater engagement than asynchronous ones.

As to format comparison, our results confirm and extend previous literature. For all societies, virtual conferences were shown to reduce impacts by 2-3 orders of magnitude across all impact categories (for GW, from an average of 941.9 kg CO_{2eq} per person to 1.0 kg), making them an indispensable option in a serious path toward decarbonization. The hybrid case study instead, with a composition of 69% virtual attendees, led to a 60% per-capita carbon footprint reduction, less than what was forecasted by previous studies assuming that the farthest attendees shift to virtual attendance (e.g., Tao et al. 2021). That cannot be enforced by academic societies without incurring discriminatory behavior, but they might design proper incentives to increase the share of virtual attendees. Beyond format shift, the study reviewed other mitigation options proposed in the literature and provided new ones to tackle venue impacts, namely the selection of a venue supplied by a district heating system (-41 kg CO_{2eq} per person from the INFORMS 2019 case) or with a green electricity contract (-1.9 kg per person from scenario analysis). We also assessed a mitigation scenario for virtual conferences, showing that if half attendees had a green electricity contract, an average reduction of 80 g CO_{2eq} per person would be achieved.

Lastly, to move the agenda forward, the study underlined several inconsistencies that affect present conference studies and proposed some avenues for future research. The most promising one, in our opinion, involves a radical change in focus while investigating the environmental impacts of scientific activities. For the environmental optimization of single conferences, studies are converging toward the multi-hub format (Klöwer et al. 2020; Tao et al. 2021; van Ewijk and Hoekman 2021). However, do we need those conferences in the first place? The core role of an academic society is arguably not to organize a conference, but to meet its members' needs, including the need to network or disseminate research. On the one hand, conferences are not the only way to meet these needs (e.g., seminar series), and on the other, different formats of communication (i.e., in-person vs virtual) meet various needs differently. Therefore, embracing a portfolio perspective, academic societies should first understand the needs of their members and then identify the optimal number and format of conferences or other activities to meet those needs while minimizing the overall environmental impacts.

Appendix: General logic and assumptions used in the LCI analysis

This Appendix provides the general logic and main assumptions used to calculate the life cycle inventory of each unit process included in the system boundary of the analyzed conferences, namely Conference organization (A.1), Venue (A.2), Exhibits (A.3), Stakeholders' transport (A.4), Catering (A.5), Accommodation (A.6), and Virtual Experience (A.7).

A.1 Conference organization

Data for the board meetings of academic societies were retrieved from interviews with society leaders. For in-person board meetings, these refer to the kilometers traveled, and guest nights spent in hotels by participating board members, while for virtual meetings, they refer to the hours of computer use. Typically, in these meetings, the annual conference is only one topic on the agenda. Therefore, we allocated only a share of previous impacts to the conference (20% as suggested by EurOMA board members).

For the organization of in-person conferences, it is common that some staff members of the organizing society visit the venue before the event. These inspection visits typically include air travel and hotel use as well. The associated values were estimated from the interviews with society leaders. Traveled distances – as for board meetings – were calculated with the same procedure detailed in Section A.4 for the transportation of stakeholders during the conference.

The hours of computer usage and kilograms of printed materials for the program committee, track/session chairs, and participants' activities were estimated by using figures from conference documents regarding the number of committee members, track/session chairs, submitters, etc., combined with per-capita consumption values based on the experience of the authors in organizing and attending conferences. The latter were further validated through interviews with a sample of distinguished colleagues within the OM&OR field. For the computer use related to the secretariat and website maintenance, we followed Hischier & Hilty (2002) and assumed 832 h and 500 h respectively.

To estimate the material consumption associated with conference materials (such as banners, programs, flyers, awards, etc.), we obtained the numbers of ordered items from conference organizers – together with product specifications where available – and multiplied them by the weights of such items (sometimes obtained indirectly from item sizes and material densities). Weights were assumed from online resources, mostly *pixartprinting.com* for stationery/promotion materials, and *amazon.com* for other materials. For the shipping – measured in tons·km – data were either provided by organizers or assumed based on total item weights and average traveled distances, as calculated in Section A.4.

Finally, for the waste generated – disaggregated into plastic, paper, and cardboard – we summed the weights of throwaway conference materials as calculated above and selected average waste treatment processes in ecoinvent.

A.2 Venue

For the *Venue* energy consumption, we adopted an indirect approach due to the absence of primary data provided by venue managers. In the conference documents, we identified all rooms, halls, and other indoor spaces used for the conferences, and in the venue websites, we retrieved the associated room sizes – in square feet or meters[4]. We, therefore, calculated the indoor used area and multiplied it by the number of conference days and the average daily energy consumption intensities specific for the building types used – in kWh/square foot·day or other energy units. Energy intensities were derived from the Commercial Buildings Energy Consumption Survey (CBECS), a national sample survey carried out periodically by the U.S. Energy Information Administration (EIA) that collects information on the stock of U.S. commercial buildings, including energy usage data by building category (EIA 2018). In absence of data regarding building energy sources, we assumed electricity from the grid and natural gas for heat production, the two most used sources in target building categories according to CBECS. We selected ecoinvent datasets related to the average grid electricity production mix in the country/region where the conferences were held and to an average heat production process using a small-scale natural gas boiler. Only for INFORMS 2019, being aware that most commercial buildings in Seattle downtown are supplied by a district heating system fueled by natural gas and wood waste (Washington State Convention Center), we selected tailored heat production datasets.

It is worth noting that energy intensities from the CBECS survey are specified on an annual basis. To calculate daily values, we simply divided them by 365, which means that energy consumption values should be interpreted as if conferences took place on an average period during the year and not on their exact period.

A.3 Exhibits

For the production, shipping, and disposal of exhibition and career fairs materials, we followed a procedure equivalent to that described above for conference materials. In this case, however, the exact number and type of ordered items were not available, and they were assumed from the interviews with organizers.

A.4 Stakeholders' transport

Great care was given to modeling *Stakeholders' transport*, as it was clear from previous studies that it would be the predominant source of impact (Astudillo and AzariJafari 2018; Neugebauer et al. 2020). Organizers provided us either with the affiliation of participants (POMS) – *case 1* – or their breakdown by country/US-state (INFORMS and EurOMA) – *case 2*. Of course, this has an impact on accuracy, with case 1 results expected to be more precise. To calculate total traveled distances per means of travel, we followed the procedure below.

In case 1, following standard practice in conference studies (see Jäckle, 2019; Spinellis and Louridas, 2013), we geolocated participants' affiliations and calculated the great circle distances from these to the venue location[5]. Based on Klöwer et al. (2020), we then assumed a modal threshold of 400 km, above which people would fly. Under the threshold, we assumed a modal split for landbound travel of 50% people traveling by car and 50% by train, as suggested by van

[4] This information is typically made available by convention centers and hotels providing event services. Differently from INFORMS and POMS conferences, the 2019 EurOMA conference was held in two university buildings. In this case, we assumed an average size for the auditoria and classrooms used by looking at the facility reports of a sample of universities.

[5] The great circle distance is the shortest distance between two points considering the earth's curvature.

Ewijk and Hoekman (2021), and corrected the great circle distances by a factor of 1.417, as empirically determined by Boscoe et al. (2012). This factor accounts for the fact that available road and railway networks constrain landbound distances to be much greater than great circle distances. Above the threshold instead, we assumed direct flights and reassessed the great circle distances using the most popular airport in the venue location as the arrival point (van Ewijk and Hoekman 2021). We further corrected them by a factor of 1.1, mediating the values empirically determined by Kettunen et al. (2005), Kim et al. (2007), and Reynolds (2014). This factor accounts for deviations from optimal routes that happen in aircraft operations due to reasons such as weather conditions, take-off/landing procedures, and restricted airspaces. For air travelers, we finally calculated the landbound connection distance from the airport to the venue location using Google Maps and assumed that 50% would take a taxi or Uber, and 50% would take the fastest public transportation option.

In case 2, the procedure was basically the same, but the most populated cities in the countries of origin (typically the capitals) were assumed as departure points, as in Desiere (2016) and Klöwer et al. (2020). INFORMS organizers gave us also the breakdown of US participants by US state, for which we considered the most populated cities within the states as departure points.

All steps above were automated in ad-hoc calculation sheets that are attached to the data collection sheets available upon request. These report the total return distances obtained by multiplying single trip distances by 2 and aggregating them by means of travel.

To model the different means of transport, we selected average process datasets in ecoinvent. For air transport, ecoinvent makes the following distinction based on flight distance: very short-haul (<800 km), short-haul (<1500 km), medium-haul (<4000 km), and long-haul (>4000 km). This is mostly done to account for the greater contribution of the take-off phase on the environmental impacts of shorter flights and the greater impacts associated with the release of emissions at high altitudes by longer flights (Kuonen 2015).

A.5 Catering

Organizers gave us the numbers and types of meals/coffee breaks served at the conferences, and the number of diners in each meal. We modeled the food consumption per person per meal type by taking the per capita consumption values provided by Neugebauer et al. (2020, Table 8), which in turn refer to a study by Jungbluth et al. (2016) on food consumption in Swiss canteens. Particularly, using those quantities, we modeled the following menu types: average menu (80% Meat/Poultry/Fish and 20% Vegetarian), vegetarian menu (100% Vegetarian), fish-based menu (80% Fish, 20% Vegetarian), and chicken and fish-based menu (80% Poultry/Fish, 20% Vegetarian). For dinner meals, we added 40 cl of average beverage items to previous menus. Modeling details are available in Table A1 below.

For coffee breaks, we assumed that 50% of diners would consume a hot beverage, of which half would take a coffee and half a tea. We further calculated 1 liter of water per person per day, as suggested by Neugebauer et al. (2020).

A.6 Accommodation

Data on hotel overnight stays were provided mostly by INFORMS in the form of hotel pick-ups by date in the hotels partnering with the conference. Through this information, we were able to infer an average of 3 nights per participant, which we also used for POMS and EurOMA conferences, being of similar duration. From the same data, we also extrapolated the rate of participants staying in budget (3 stars) and upmarket (4 stars) hotels – 7% and 93% respectively – and selected tailored ecoinvent datasets related to the operation of these building types.

Material	**Sub-Material**	**Specification from ecoinvent**	**Value per person**	**Unit**
		Meals		
Meat	Swine	Swine for slaughtering, live weight (GLO)	36	g
	Red meat	Red meat, live weight (GLO)	36	g
Poultry	Chicken	Chicken for slaughtering, live weight (GLO)	36	g
Fish	Generic	Marine fish (GLO)	21	g
Vegetarian supplements	Soy	Soybean (RoW)	43	g
	Cheese	Cheese, from cow milk, fresh, unripened (GLO)	43	g
	Representative vegetable (corn)	Sweet corn (GLO)	43	g
Fresh vegetables	Tomato	Tomato, fresh grade (GLO)	62	g
	Zucchini	Zucchini (GLO)	62	g
	Potato	Potato (GLO)	62	g
	Sweet corn	Sweet corn (GLO)	62	g
	Lettuce	Lettuce (GLO)	62	g
Eggs	Eggs	Consumption egg, at farm/NL[a]	5	g
Durable goods	Rice	Rice, non-basmati (GLO)	68.5	g
	Pasta	Wheat flour mix (GLO)	59.9	g
	Pasta	Tap water (GLO)	28.5	g
Bread	Flour	Wheat flour mix (GLO)	83	g
	Water	Tap water (GLO)	20	g
	Sugar	Sugar, from sugar beet (GLO)	5	g
Dairy products	Yogurt	Yogurt, from cow milk (GLO)	15	g
	Cream	Cream, from cow milk (GLO)	45	g
	Cheese	Cheese, from cow milk, fresh, unripened (GLO)	45	g
	Milk	Cow milk (GLO)	30	g
Sweets	Flour	Wheat flour mix (GLO)	8	g
	Milk	Cow milk (GLO)	6	g
	Cocoa	Cocoa bean (GLO)	2	g
	Oil	Palm oil, refined (GLO)	4	g
	Eggs	Consumption egg, at farm/NL[a]	6	g
	Sugar	Sugar, from sugar beet (GLO)	6	g
Fruit	Apple	Apple (GLO)	10	g
	Banana	Banana (GLO)	8	g
Non-food	Serviettes	Tissue paper (GLO)	0.8	g
Beverages	Generic beverages	27 Beverages, EU27[b]	0.4	kg
		Coffee Breaks		
Hot beverages	Coffee	Coffee, green bean (GLO)	10	g
	Tea	Tea, dried (GLO)	3	g
	Water	Tap water (GLO)	0.2	kg

Table A1 – Food consumption per person-meal (adapted from Neugebauer et al., 2020)

[a] LCI data from the Agri-footprint 5 database (Paassen et al. 2019)

[b] LCI data from the EU Input Output database

Figure A1 in the next page displays the average LCIA indicator results per *guest·night* for different accommodation options modeled in ecoinvent, namely hostels, budget hotels (3-stars), upmarket hotels (4-stars), and luxury hotels (5-stars).

A.7 Virtual experience

EurOMA recorded precise data regarding the time participants spent attending the live sessions during the conference – all broadcasted within the virtual platform hosting the event – and watching the recordings after it.

INFORMS instead provided us with analytics data regarding the time participants spent logged in to the conference platform. These data describe well the extra conference activity (mostly abstract reading and recordings' views), but not as well the live conference activity because in this case many sessions were hosted in Zoom outside the platform. For the 2021 hybrid event, we also obtained the attendance count for Zoom sessions, which allowed us to derive precise estimates. These figures, however, were not extrapolatable to the 2020 virtual event due to the different design (different session duration and additional presence of in-person attendees in 2021). For the 2020 virtual event, we therefore combined platform analytics data with observations from the organizers and derived an average value for the per capita live attendance time – 2.25 h per person – which we multiplied by the number of attendees.

For POMS 2021 virtual conference, no primary data were available. Being the conference size and design in between those of EurOMA and INFORMS virtual conferences, we estimated average per capita values for live attendance and extra conference platform visits by mediating those of other conferences. We then multiplied these values by the number of attendees.

We finally selected ecoinvent datasets modeling the use of a laptop computer connected to the internet network. Platform analytics data revealed that this was the predominant type of device used, with tablets and mobile phones accounting cumulatively for only 1-4% of the use time at INFORMS and EurOMA conferences. Ecoinvent datasets model specifically the use of hardware (laptop, internet devices) and energy consumption for one hour using broadband access, not including the operation of remote servers and other devices making up the internet network, whose consumption and allocation to the single user is affected by great uncertainty and time variability (Coroama et al. 2013). That means our estimations are conservative as compared to other studies that tried to capture the impacts associated with those devices (e.g., Tao et al. 2021).

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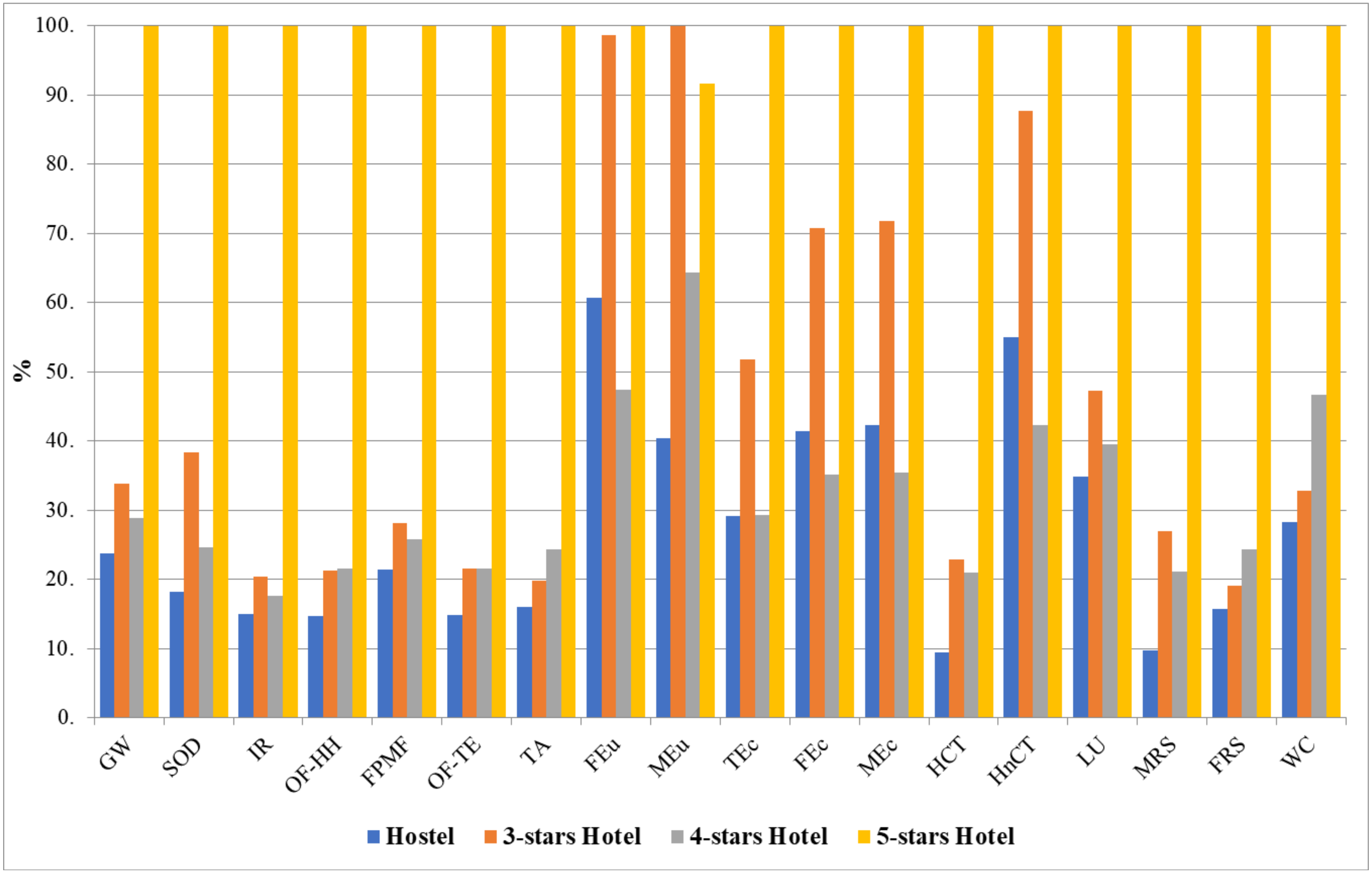

Figure A1 – LCIA impact indicators per guest·night for accommodation options modeled in ecoinvent (Wernet et al. 2016)

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