Journal of Cleaner Production 368 (2022) 133174

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Decarbonizing the academic sector: Lessons from an international research project

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ARTICLE INFO

Handling Editor: Cecilia Maria Villas Bôas de Almeida

Keywords:
Air travel
Carbon budget
Commuting
International mobility
Paris agreement

ABSTRACT

Research activities generate considerable carbon emissions. Some universities and research centers have implemented voluntary measures to reduce academia's carbon footprint. To contribute to the debate on pathways to decarbonize the academic sector, this work calculates the carbon emissions of an international research project in relation to 1) research-related travel, 2) researchers' non-business travel derived from the international nature of the team, 3) researchers' commuting, and 4) project's digital footprint. The work then simulates the project's carbon potential reduction under two scenarios and discusses emissions reduction alternatives and their potential side-effects. The project examined emitted an estimate of 161 tons CO_2-eq, which could have been largely reduced to 92 tons CO_2-eq (or 53% of the emissions) by applying a standard set of measures already proposed by scholars aiming to decarbonize research ("Reduced emissions scenario") or to 4 tons CO_2-eq (or 2.4% of the estimated emissions) by applying more strict measures aiming to reach carbon neutrality ("Net-zero emissions scenario"). Most emissions reductions come from reducing travel. While the measures proposed could indeed save a substantial amount of emissions, they might have also impacted project's academic outputs, economic costs, and researcher's work-life balance. Although collateral impacts of decarbonizing measures are yet little understood, they are likely not negligible and should be considered in a decision-oriented context to discern acceptable from unacceptable rules. The article discusses reliance on individual or voluntary action as the major bottlenecks that hamper the application of measures to decarbonize the academic sector and calls for the development of normative standards of scientific research practice that encourage, value or even impose the reduction of carbon emissions.

1. Introduction

Awareness is growing on the carbon emissions generated by research activities (e.g., Ciers et al., 2018; Tao et al., 2021; Waring et al., 2014), although researchers lack estimations of the relative contribution of different activities to their carbon footprint and guidance on how to minimize them (e.g., Passalacqua, 2021). As scientists are often frequent travelers (Ciers et al., 2018; Kjellman, 2019) and as travel related to research activities (e.g., field work, research dissemination and outreach) is one of the main sources of carbon emissions in the sector (Ciers et al., 2018), most attention on the topic has focused on the impact of air travel to attend scientific activities including fieldwork and, particularly, scientific conferences (Achten et al., 2013; Ciers et al., 2018; Kjellman, 2019). Indeed, it is estimated that the average carbon footprint of each participant in a scientific event reaches up to 3000 kg CO2, placing the annual carbon footprint for the global event industry on the same order of magnitude as the yearly GHG emissions of the United States (Tao et al., 2021).

Other research-related activities and behaviors, such as the growing internationalization of the academic sector, researchers' commuting habits or internet use also contribute to the academic sector carbon impact. While mobility has always been inherent in researchers' careers and is generally positively valued (Glover et al., 2018; Grantham, 2018; Kim, 2017; Wynes et al., 2019), globalization and higher education expansion have now accelerated it to unprecedented levels (Tzanakou and Henderson, 2021). However, some critical voices have started to

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https://doi.org/10.1016/j.jclepro.2022.133174
Received 22 June 2021; Received in revised form 2 June 2022; Accepted 14 July 2022
Available online 18 July 2022

question the conceptual certainties inherent to discourses around academic mobility, including its environmental impacts (Tzanakou and Henderson, 2021). Nevertheless, with the exception of some work on the environmental footprint of international students (Arsenault et al., 2019), there are no estimates of the carbon footprint of the internationalization of research activities.

There is also scant information on the carbon impact of researchers' commuting habits and internet use and how to minimize them. Recent work shows that teleworking reduces commuting carbon emissions (Brömmelhaus et al., 2020; Emre and De Spiegeleare, 2019), although the real impact of these reductions might be overstated once increase in home-energy use (e.g., air conditioning, lighting, electronics, and appliances) and other rebound effects are considered. Similarly, the impact of researchers' generalized increase in the use of video-conferencing and digital technologies (Obringer et al., 2021) is poorly known. It is estimated that the use of Information and Communication Technologies (ICT) accounts for around half of the electricity used at home. In that sense, reducing commuting while increasing digital footprint will result in lower environmental benefits when researchers are located in regions with a strong dependence of non-renewables in the power grid (Tao et al., 2021). This is particularly the case for video-conferencing, as internet traffic due to high-definition videos has important and increasingly growing environmental impacts (Masanet et al., 2020; Obringer et al., 2021).

The growing awareness of the carbon emissions of research activities has led some researchers to advocate for a serious reduction of academia's carbon footprint (Jean and Wymant, 2019; Kjellman, 2019; Klöwer et al., 2020) and some universities and research centers to implement related institutional measures (see Annex 1). Given the importance of air travel in the academic sectors (Ciers et al., 2018), proposed measures have often focused on reducing travel-related carbon emissions. Measures proposed range from allowing the compensation of carbon emissions associated with flights, to incentivizing train travel, avoiding layovers, limiting reimbursement of short-distance flights, reducing conference attendance, or allocating individual carbon budgets (see resources in Annex 1). Research shows that these measures alone can lead to a substantial reduction of emissions. For example, Ciers et al. (2018) find that simple measures such as restricting air travel to economy class, replacing short trips by train, and avoiding layovers can reduce academia's travel-related carbon emissions by 36%. In the same line, researchers are also advocating transitioning from in-person to virtual conferencing (e.g., Passalacqua, 2021), which can substantially reduce the carbon footprint by up to 94%, or using hybrid conferences with carefully selected hubs that could maintain more than 50% of in-person participation, while reducing carbon footprint and energy use by two-thirds (Tao et al., 2021). Beyond travel, other measures have been proposed to reduce research-related emissions, such as increasing teleworking (Hook et al., 2020) and limiting the use or the quality of video during online meetings (Obringer et al., 2021).

A strong set back to the implementation of initiatives to reduce carbon emissions of the academic sector is reliance on voluntary action within a community that highly values international connections (Arsenault et al., 2019; Sallee and Lewis, 2020). The scientific community emphasizes the importance of international collaborations and relies on conference and workshop attendance to establish and strengthen relations between researchers (Glover et al., 2018). Consequently, some scientists worry that travel reductions might impact their professional networks and careers (Wynes et al., 2019). Indeed, international mobility is increasingly demanded in the academic sector, particularly for early-stage researchers (Bauder, 2015; Grantham, 2018). Moreover, as research mobility increases, also does personal mobility, the paradigmatic example being the growing number of dual career couples in academia that live far apart and regularly travel to visit each other (Bauder, 2015; Grantham, 2018). Caught between the personal interest and the group benefit, researchers lack information on the impact of their different activities on carbon emissions as well as guidance on efficient strategies to reduce them. Such information would contribute to identify potential pathways to decarbonize the academic sector.

To explore the differentiated impact of research activities on carbon emissions, this work calculates the carbon emissions of an international research project and discusses emissions reduction alternatives and their potential side-effects. The calculations include emissions associated with 1) research-related travel, 2) researchers' non-business travel derived from the international nature of the team, 3) researchers' commuting, and 4) project's digital footprint. Then, to explore activities' potential to contribute to reduction emissions efforts, the article simulates the potential for emissions reduction under two scenarios adopting measures oriented to reduce carbon footprint. Beyond carbon emissions reduction, the potential impacts of the measures on academic outputs, economic costs, and researchers' work-life balance are also discussed. Finally, this work highlights major institutional and social bottlenecks to implement the proposed measures and provides recommendations for actions that might contribute to decarbonize the academic sector.

2. Materials and methods

2.1. The case study

This work quantifies the carbon emissions associated with different activities undertaken by participants of the '*Local Indicators of Climate Change Impacts: The Contribution of Local Knowledge to Climate Change Research*' (LICCI; www.licci.eu) project during its initial phase (June 2018–December 2019). LICCI is an international research project hosted at the Institute of Environmental Science and Technology of the Autonomous University of Barcelona (ICTA-UAB), Spain. The project studies the potential of Indigenous and local knowledge systems to improve the understanding of climate change impacts on social-ecological systems (Reyes-García et al., 2019). While the setting of the project responds to its particular research goals, three different traits make of the LICCI project a good case study to discuss pathways to decarbonize the academic sector. First, given the research topic, LICCI core team member constitute a group of researchers legitimately concerned with climate change impacts, and willing to provide the data required for this work. Second, as most researchers across the world, LICCI project members commute and use internet, which make some parts of the analysis presented here largely generalizable to any research field. Finally, following a growing research trend, the LICCI project aims for global research findings, which necessarily implies communication across distant places and reliance on a highly international research team.

During the analyzed phase, LICCI staff included 10 researchers at different career stages (one PI, one project manager, one computer scientist, four post-doctoral researchers, and three PhD candidates) from six nationalities, and two external consultants. During the initial phase, LICCI core team members settled in the host institution (ICTA-UAB, Spain), developed and field-tested data collection protocols (Reyes-García et al., 2020) and worked in the selection and training of project partners. LICCI partners are external researchers (i.e., Ph.D. students, early career scholars, or practitioners) who share the project's scientific interests and motivations and commit to collect project data in a particular field site. Field sites were selected aiming to maximize variability across climatic zones (e.g., tropical, temperate, cold) and livelihood activities (e.g., fishing, farming, pastoralism). At the time of the analysis, the LICCI network included 53 members (10 core members, 2 consultants, and 41 partners) working in 46 field sites in 34 countries (5 from core members and 41 from partners). A requisite for participation was that all partners attended a one-week face-to-face methods training workshop which took place at the host institution (ICTA-UAB, Spain).

2.2. Data collection and analysis

The analysis focuses on the initial 18-month period of the project, from its official start (June 2018) to the end of the initial phase (December 2019), when travel had not yet been disrupted by the COVID-19 pandemic. The estimations of carbon emissions consider emissions from 1) research-related travel, 2) researchers' non-business travel associated with the international nature of the research team (hereafter, international mobility), 3) researchers' commuting habits, and 4) project's digital footprint.

Research-related travel: Information on national and international business trips (i.e., trips derived from work done to the LICCI project and payed by the project) conducted during the project's initial phase was compiled. For each trip, the following was included i) mode of transport (i.e., train, plane, bus, car); ii) travel reason (i.e., training, conference/workshop, fieldwork, other), and iii) journey information (i.e., departure, layover, and destination). All flights were done in economy class. To calculate flight and train related emissions, the mix of methods described in Barret (2020) was followed. In order to reduce method-related bias, flight GHG emissions in tons of carbon dioxide equivalent (CO_2-eq) were estimated as the average of the results of the following emission methods: Atmosfair, ADEME, MYCLIMATE, DEFRA, French Ministry of Ecology, KLM data best fit, and ICAO data best fit. To calculate train and bus emissions in ton of CO_2-eq, DEFRA's average for national and international emission factors, 23.1 and 103.12 g CO_2-eq per passenger/km (reported in Barret, 2020) was used.

International mobility: We also collected information on national and international non-business trips associated with the international composition of the team (e.g, relocation, trips to visit family or partners and not paid by the project) conducted during the project's initial phase. To assess the carbon footprint of non-business travel, an internal survey asking LICCI core members about their travel during the initial phase of the project was conducted. The survey included ***i)*** relocation (i.e., travel to Barcelona to join the project) and non-business trips done to visit ***ii)*** spouse/partner or ***iii)*** close family located in other cities or countries. For each trip, we collected information on the distance travelled and on the mode of transport used (i.e., train, bus, plane and car). The amount of CO_2-eq emitted was calculated using the same method than for research-related travel.

Commuting: To assess the carbon footprint of LICCI core team members' commuting habits, an internal survey was conducted. The survey included ***i)*** the number of days/week regularly commuted to work, ***ii)*** the distance travelled, and ***iii)*** the mode of transportation used (i.e., car, bike, train or bus). An online tool, i.e., the carbon footprint calculator (https://www.carbonfootprint.com/calculator.aspx), was used to estimate the CO_2-eq emitted during commuting. This calculator follows a methodology outlined by the UK Government, and currently uses the "Greenhouse gas reporting: conversion factors 2019".

Digital footprint: To estimate the project's digital footprint, only the impact of ***i)*** the project's website and ***ii)*** videoconferences were considered. To assess the carbon impact of a visit to the website, the project used an online tool (https://www.websitecarbon.com) that considers the amount of data transferred, the energy intensity of web data, the energy source used by the data center, the carbon intensity of electricity, and the website traffic to provide an estimate of the carbon emitted by a webpage/visit. Since the project website has 12 different pages, each with a different emission impact, but data on number of visitors to each page was not available, the average impact of the 12 pages in the LICCI website at the time of research (0.83 gCO_2-eq) was calculated, assuming the standard visitor would browse through 6 of the 12 pages in the website. The estimated impact of a visit was then multiplied by the total number of visits to the website during the period analyzed.

Carbon emissions associated with teleconferences were estimated using recent published estimates of data transferred during teleconferences per participant/hour. Such measures estimate that a 1-h standard-definition video call consumes about 270 MB per person, whereas a 1-h audio call consumes about 36 MB per person (Aslan et al., 2018; Obringer et al., 2021). For the 2019 Catalan energy grid, a 0.008 kWh/GB internet intensity and a 321 gCO_2/kWh carbon footprint were considered (Oficina Catalana del Canvi Climatic, 2019). The carbon emissions associated with teleconferences were calculated for an average of 1 h/day for the 10 core members during the 250 working days included in the initial phase.

2.3. Building scenarios to calculate project's carbon emissions reduction potential

Calculations were repeated under two different scenarios designed to reduce project's carbon emissions (Table 1). The first scenario, "reduced emissions", estimates carbon emissions assuming the implementation of measures which have already been proposed in emissions reductions initiatives by universities or other institutions (Annex 1). The second scenario, "net-zero emissions," explores measures needed to reach carbon neutrality.

Reduced emissions scenario: The first scenario explores the project's carbon reduction potential through the implementation of measures that have already been proposed to decarbonize academia (e.g., Ciers et al., 2018). The criteria used to re-calculate carbon emissions associated with research-related travel include changes in 1) the *mode of transport* (i.e., using the train for trips <800 km); 2) the *number of travellers* (i.e., restricting participation to one core member per activity); and 3) the *activities involving travel*. In particular, this scenario recalculated emissions related to the organization of partners' training under the assumption that training could have occurred in five regional hubs (i.e., Barcelona, Delhi, Nairobi, New York and São Paulo) instead of centralizing training at the host institution (Barcelona) (Fig. 1). Potential emissions were estimated assuming that partners would have attended the training closer to their home institution and that three LICCI core team members would have travelled from Barcelona to the regional hub to deliver the trainings. When possible, direct flights between partners' home institution and the hub proposed for the training

Table 1
Criteria used to calculate LICCI project carbon emissions under different scenarios.

Category	Estimated emissions	Reduced emissions scenario	Net-zero emissions scenario
Research-related travel	- Use fastest and cheapest trip.	-Use train for all trips <800 km.	-Restrain short-term travel to train.
	-Allow travel of all researchers interested in an activity (i.e., conference, fieldwork).	-Take direct (no-haul) flights when available.	-Allow flights only for long-term unavoidable activities (i.e., fieldwork >6 months).
	-Conduct face-to-face partner's training at the host institution.	-Selective participation of one core staff/activity (i.e., conference, fieldwork).	-No travel for training (training would have been conducted online)
		-Decentralize face-to-face partner's training in five continents.	
International mobility	-International team.	-European team.	-Spanish team.
Commuting	-Daily commuting to office.	-Telework one day/week.	-Telework four days/week.
Digital footprint	-No restrictions on website size and medium size images on the website.	-Half the number of pages and size of images in website.	-Reduce website to only one webpage.
	-Unlimited use of video during virtual meetings.	-Maintain video off during virtual meetings except when speaking.	-Use only voice calls for virtual meetings.

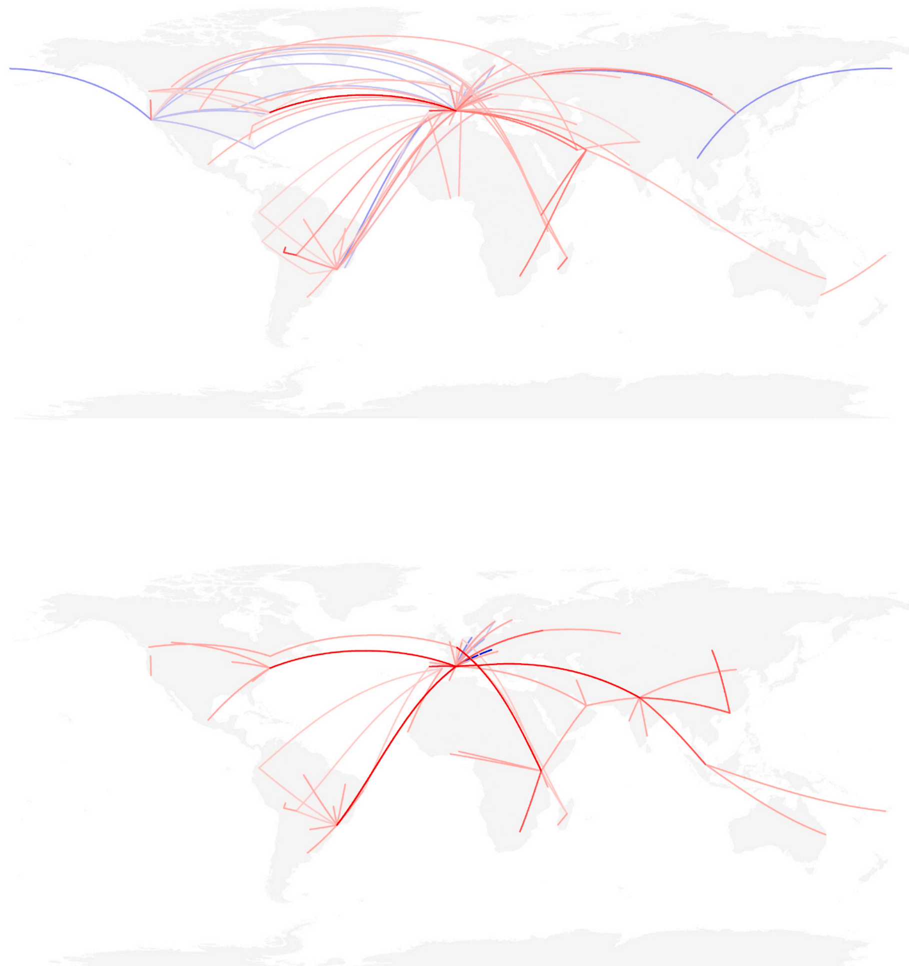

Fig. 1. Differences in the distribution of air travel in the estimated emissions (top) and reduced emissions scenario (bottom). Red and blue lines indicate travel related with research activities and international mobility, respectively. Darker colors indicate stretches that are flown more frequently.

were assumed.

Measures regarding international mobility included hiring only European staff as core team members, the assumption being that the distance travelled for relocation and non-business trips to visit partners or families would be lower for a European than for a fully international team. To calculate the impact of the international mobility of a European team, the average carbon emissions of European members were extrapolated to the other international members of the team (i.e., non-European members). Measures regarding core staff commuting habits include introducing teleworking one day/week.

Finally, measures regarding the project's digital footprint include 1) redesigning the website to reduce to half (i.e., six) the number of pages and assuming the same number of visitors, but who would only browse through three pages and 2) assuming the number of hours in virtual meetings would remain the same, but video would be used only half of the time. Since this scenario included measures for selective participation of core team members in conferences, the assumption was made that members who could not attend the meeting in person would attend virtually. Thus, the estimated carbon emissions of virtual participation in conferences were added, assuming 7 h of video call during three days for each participant/conference.

Net-zero emissions scenario. The second scenario explores measures required to reach carbon neutrality. Under this scenario, the only air travel allowed are long-term trips (> six months) conducted for fieldwork or research stays. The rest of activities involving travel were substituted by virtual activities (see below). Measures to reduce carbon emissions associated with the international mobility included hiring a national (i.e., Spanish) team. For the calculations, the average carbon emissions of Spanish members were extrapolated to the whole team. Measures regarding core staff commuting habits included introducing teleworking four days/week. Finally, rules regarding the project's digital footprint include 1) maintaining only one page in the website (calculated as the average emissions for all the webpages used in the estimated emissions) and assuming the same number of visitors, and 2) using only voice calls during teleconferencing. Calculation of emissions for teleconferencing under this scenario relate to a) researchers' meetings, b) partners' training, and c) conference attendance. To calculate the digital footprint of researcher's meetings, an increase to 2 h/day in virtual meetings was assumed, to substitute for in person activities. Additionally, this scenario assumes that partners would be trained online and conference attendance would always be virtual. The calculation of emissions related to the online training considers the data transmitted during an 1 h voice call (36 MB), the total number of training hours (35 h), and the number of participants (42 partners+10 staff). The carbon footprint of all the conferences attended was also added, assuming 7 h voice call during three days for each conference.

2.4. Comparing scenarios

Results from the three calculations (i.e., estimated emissions, reduced and net-zero emissions scenarios) are compared considering both the total and the relative reduction in carbon emissions. The analysis of emissions and reduction potential is done according to the different categories selected (i.e., research-related travel, international mobility, commuting and digital footprint). "Reduction potential" refers to the percentage difference between the estimated carbon emissions and the emissions calculated under the different scenarios. Given the estimative nature of the calculations, values were rounded and non-integer numbers were only shown for values < 1.

2.5. Methodological limitations and biases

Calculating carbon emissions with accuracy is a complex process and that the numbers presented below are just rough estimations subject to several limitations and biases. An important limitation of this work is the lack of accuracy on travel-related emissions. Calculations of travel-related carbon emissions largely vary according to the method used. For example, in the calculations included here, the emissions of a flight between Barcelona and Oran ranged between 94 and 360 tons CO_2.eq (382%), depending on differences in the use of parameters like altitude reached or type of aircraft. For the purpose of this work, the average of the selected methods was used (see Barret, 2020), but there is uncertainty in the calculated emissions. Another limitation of this work refers to the omission to include carbon emissions associated with some activities conducted during the initial phase of the project (e.g., in-country travel during fieldwork, storage of data in the cloud), as well as of emissions associated with the functioning of offices (i.e., electricity, heating system). The omission of these categories results in an underestimation of the carbon emissions of the project.

Additionally, a potentially important source of bias is the lack of real data to calculate emissions in some of the categories. Thus, data were not collected on days commuted or on time spent on video conferences for which the calculation regarding emissions associated with commuting and digital footprint rely on recalls and assumptions, potentially introducing biases in the calculations. Moreover, the category on "digital footprint" misses estimations of some used of digital facilities, such as using computers (and others) for communication (e.g., mail) or use of cloud storages.

In sum, the estimations presented here have a low level of accuracy and probably differ from real emissions in unknown magnitude and direction. However, as the methods and assumptions used remained the same for the different scenarios, they provide us with values for the selected categories that are relevant in terms of comparison. The values obtained are also significant to discuss impacts and bottlenecks of potential measures oriented to decarbonize research, which is the main goal of this work.

3. Results

3.1. Estimated emissions

The estimations show that, during the initial phase, the LICCI project emitted a total of 161 tons CO2-eq (Fig. 2). Most of these emissions derive from research related travel (121 tons CO_2-eq or 75.6% of the estimated emissions) and international mobility (32 tons CO_2-eq or 19.8%). Commuting (4.4%) and digital footprint (0.1%) add to less than 5% of the emissions (Fig. 3).

During the initial phase of the project, LICCI core team members and partners conducted several activities requiring travel, including fieldwork, attendance to training, conferences and workshops, and other activities. Of the estimated emissions of research related activities, 85 tons CO_2-eq (52.6% of the total) correspond to partners' attendance to the training event in Barcelona, 20 tons CO_2-eq to conference attendance by core team members, and 16 tons CO_2-eq to travel for fieldwork by core team members. Most of the research-related travel emissions were done by air travel (122 tons CO_2-eq), with travel by train contributing only to 0.07 tons CO_2-eq.

LICCI core team members travelled from their place of origin to the host institution to take their jobs, some of them travelled back home to visit family, and a few of them regularly travelled to other Spanish cities or internationally to visit partners. The activities that contributed the most to emissions in this category included travel to visit family (15 tons CO_2-eq or 9.2% of the total) and partners (11 tons CO_2-eq or 6.6%). Emissions associated with the incorporation to the project added 6 tons CO_2-eq. Most of the emissions were done by traveling by plane (31 tons CO_2-eq), with travel by train adding 0.43 tons CO_2-eq.

LICCI core team members used train (7 people), car (3 people), bus (1) and bicycle (1) to commute to office, some of them combining two modes of transport. All researchers, except three, commuted to office daily covering distances between 2 and 90 km one way (avg. 21.25 km per person/trip). Two people worked only 4 days, and the person traveling the longest distance (90 km) teleworked 3 days/week. The estimated carbon emissions due to commuting result in 7 tons CO_2-eq, of which 5 tons CO_2-eq come from car emissions and 2 tons CO_2-eq are associated with other modes of transport.

The estimated carbon emission of a visit to the website is 4.97 gCO2-eq. Since the website received 40.618 visits from the moment the webpage was launched until December 2019, visits to the project website represented 0.20 tons CO_2-eq. Finally, the assumptions for teleconferencing resulted in an estimation of 1733 gCO_2-eq, or 0.0017 tons CO_2-eq.

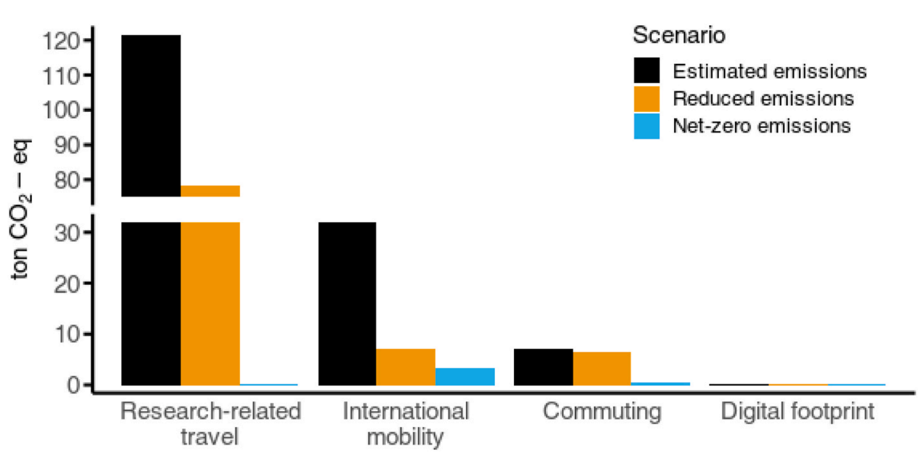

Fig. 2. Estimations of carbon emissions (in tons CO_2-eq) during the preparation phase of the LICCI project under three scenarios, divided by emissions categories.

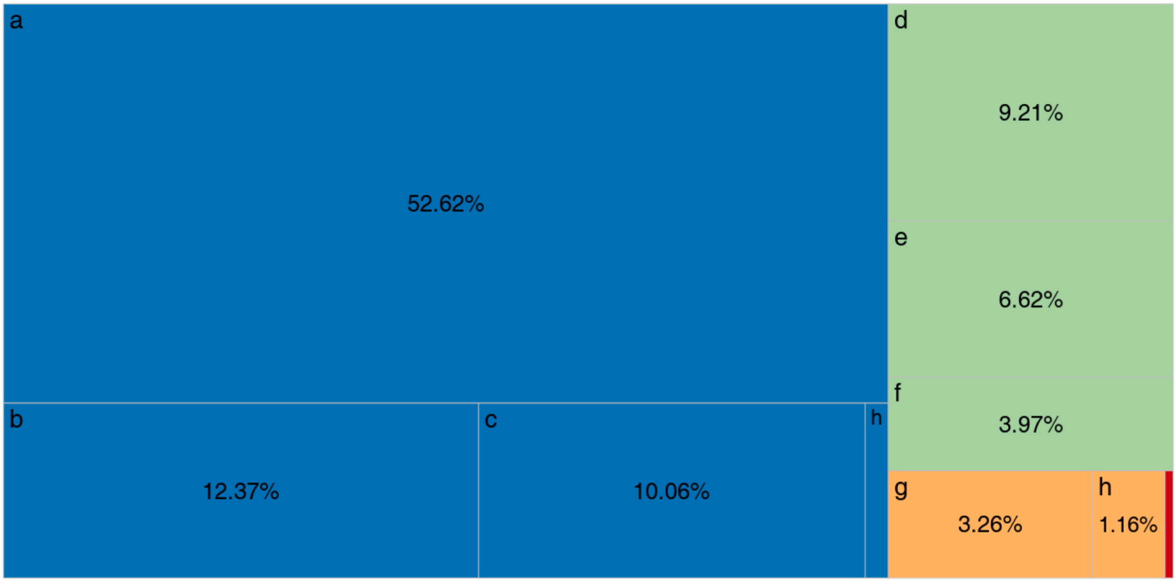

Fig. 3. Relative contribution of different emissions categories to the total estimations of carbon emissions during the preparation phase of the LICCI project. Blue represents research-related travel (a: training; b: conferences; c: fieldwork); green represents international mobility (d: visit family; e: visit spouse/partner; f: relocation); orange represents commuting (g: car; h: other); and red represents digital footprint. Numbers indicate the relative contribution (%) of each category to the total estimated emissions.

3.2. Reduced emissions scenario

Applying the measures proposed in the reduced emissions scenario would have resulted in the emission of a total of 92 tons CO_2-eq, which represents 57.3% of the estimated emissions (Fig. 2). In this scenario, the relative weight of the different categories resembles their relative weight in the estimated emissions (Fig. 4, Fig. 3). Overall, in this scenario, research-related travel would represent 85% of the emissions and having a European team would reduce the share of emissions associated with international mobility to 7.7%. Comparatively, commuting would represent a highest share of the emissions (7%), particularly associated with commuting by car (5.4%; Fig. 4).

Measures proposed in this scenario would have resulted in a reduction of the carbon emissions of research-related travel by 35.4%, from an estimate of 121 to 79 tons CO_2-eq (Fig. 5). Decentralizing the face-to-face partners' training would have resulted in the emission of 59 tons CO_2-eq, compared to the 85 tons CO_2-eq in the estimated emissions. In this scenario, emissions associated with conference attendance and fieldwork would also be reduced by about half: from 20 to 10 tons CO_2-eq for conference attendance and from 16 to 9 tons CO_2-eq for fieldwork. In this scenario, most emissions in the research-travel category continue to be associated with air travel (78 tons CO_2-eq).

Hiring a European-only team would have resulted in additional emissions reductions, from 32 to 7 tons CO_2-eq in the international

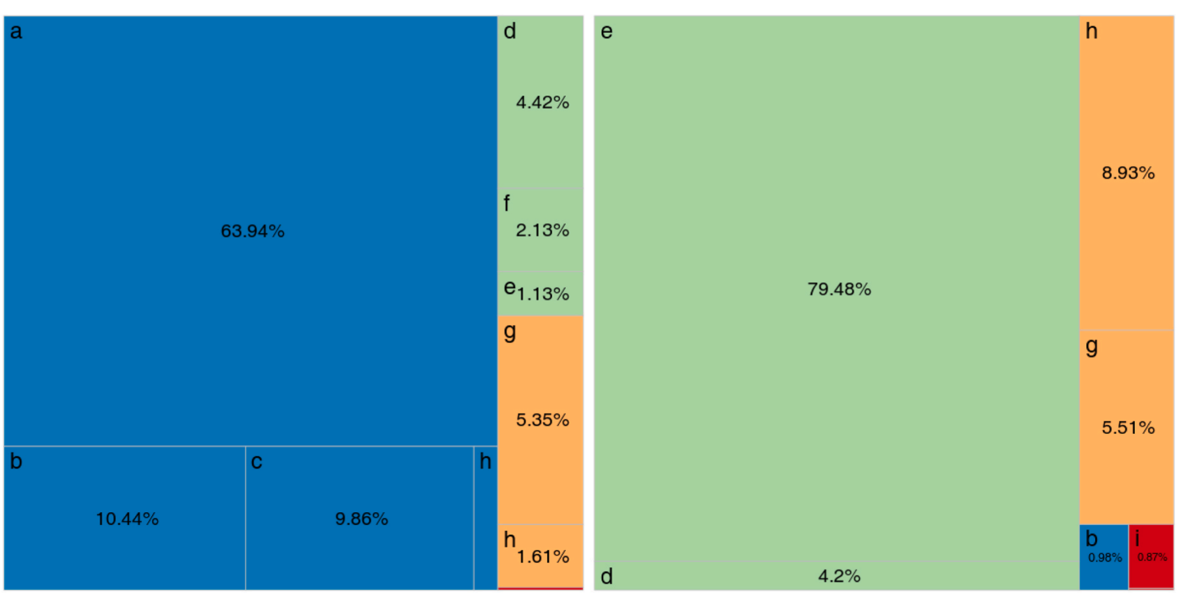

Fig. 4. Relative contribution of different emissions categories to the total estimations of carbon emissions during the initial phase of the LICCI project under the reduced (left) and net-zero (right) emissions scenarios. Blue represents research-related travel (a: training; b: conferences; c: fieldwork); green represents international mobility (d: visit family; e: visit spouse/partner; f: relocation); orange represents commuting (g: car; h: other); and red represents digital footprint (i: website). Numbers indicate the relative contribution (%) of each category to the total estimated emissions in each scenario.

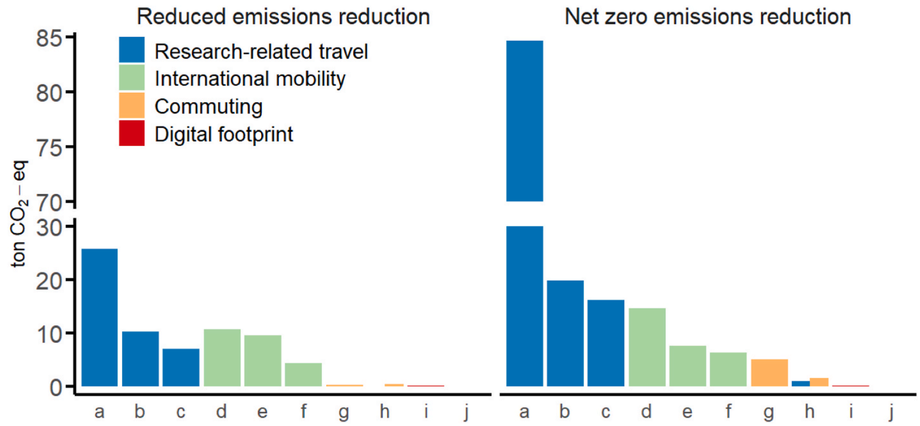

Fig. 5. Potential carbon emissions reduction (in ton CO_2-eq) during the initial phase of the LICCI project under the reduced (left) and net-zero (right) emissions scenario, divided per emissions category. Blue represents research-related travel (a: training; b: conferences; c: fieldwork); green represents international mobility (d: visit family; e: visit spouse/partner; f: relocation); orange represents commuting (g: car; h: other); and red represents digital footprint (i: website; j: teleconferencing).

mobility category. Specifically, emissions associated with visit to family would have been reduced from 15 to 4 tons CO_2-eq and emissions associated with visit to partners from 11 to 1 tons CO_2-eq. Emissions associated with incorporating staff to the project would have been reduced from 6 to 2 tons CO_2-eq. In this scenario and category, most emissions continue to be associated with air travel (7 tons CO_2-eq).

Teleworking one day per week would reduce carbon emissions from 7 to 6.3 tons CO_2-eq during the period examined, from which 4.9 tons CO_2-eq would be due to commuting by car and 1.4 tons CO2-eq to commuting with other transports.

Measures proposed for this scenario would result in an overall reduction of the project's digital footprint despite the increase of the digital use. The measures proposed could reduce the estimated carbon emission of a visit to the website from 4.97 to 1.66 gCO_2-eq, representing a potential reduction from 0.20 to 0.067 tons CO_2-eq. In relation to the use of teleconferencing, having the video turned off except when speaking, represents a potential reduction from 0.0017 to 0.00098 tons CO_2-eq. Overall, the measures included in this category would represent a reduction on CO_2-eq emissions, even with the increase of teleconferencing (i.e., including virtual attendance to conferences).

3.3. Net-zero emission scenario

Applying the measures proposed in the net-zero emissions scenario would have resulted in the emissions of 4 tons CO_2-eq, or only 2.4% of the estimated emissions (Fig. 4). In this scenario, the category with the largest share of carbon emissions would be international mobility (83.7%) followed by commuting (14.4%). The categories of research-related travel and the digital footprint would contribute to less than 1% of the emissions each.

The generalization of travel restrictions would drastically reduce the project's carbon emissions (Fig. 5). Under the measures applied in this scenario, only some train travel for conference attendance would have occurred, resulting in the emission of 0.04 tons CO_2-eq. Hiring a team of Spanish researchers would have resulted in additional reductions of CO_2-eq emissions. Interestingly, visits to partners would still result in 3 tons CO_2-eq and visit to family in 0.16 tons CO_2-eq, given that Spanish team members also travel long distances to visit family or partners. In this scenario, 2 tons CO_2-eq would be generated by air travel and 1 ton CO_2-eq by train travel.

Generalizing teleworking to four days/week would reduce carbon emissions during the period examined from 7 to 0.5 tons CO_2-eq, from which 0.21 tons CO_2-eq would result from commuting by car and 0.34 tons CO_2-eq from commuting with other transports. Finally, keeping only one page in the website represents a potential reduction from 0.20 to 0.033 tons CO_2-eq. Emissions related to staff meeting would reach 462 gCO_2-eq, considering a double in the number of hours teleconferencing -due to teleworking- but systematically using voice calls. Emissions related to partner's training would represent 210 gCO_2-eq. Finally, emissions related to virtual conference attendance would represent 21 gCO_2-eq. Overall, the digital footprint of the project under this scenario would reach 0.001 tons CO_2-eq.

4. Discussion

According to the estimations, during the 19 month-period of preparation, the LICCI project emitted about 161 tons CO_2-eq. Considering an EU-27 per capita average carbon footprint of 6.7 tons CO_2-eq per year in 2019 (Eurostat, 2021), the preparation phase of the project equals to the average yearly emissions of 24 European citizens.

The estimations show that most of the project emissions correspond to travel, and mainly air travel. In fact, although air travel represents 2–3% of CO_2 emissions at the global level (Lee et al., 2021), travel represented about 75% in the estimated emissions of the preparation phase of the LICCI project, which is in line with the estimated percentages of air travel for research-related emissions (Stohl, 2008). Importantly, research-related and personal travel are the two categories with the highest reduction potential (Fig. 5). For example, in relation to research-related travel, the first scenario shows that the application of travel reduction measures, most of them already discussed in the literature, would have represented an overall reduction of 42.7% of project emissions. In other words – alone-the application of travel reduction measures to research-related travel would have suffice to align the project with the EU pledge on the Paris Agreement to reduce EU emissions by "at least 40%" by 2030. In the same line, the application of the restrictive measures proposed under the net-zero emission scenario would have aligned the project with the EU objective to cut emissions by 80–95% in 2050.

International mobility, also implying travel, is the second most impactful category in terms of carbon emissions. The calculations suggest that the highly international core team emitted 32 ton CO_2-eq (or about 20% of the estimated emissions) in trips done to visit their family and partners/spouses in the country and/or abroad. Interestingly, while changing the composition of the team (i.e., from a highly international to a Spanish only team) would have helped to reduce carbon emissions, the net-zero emissions scenario suggests that emissions in this category would continue to represent a high share, as Spanish members of the team also travel to visit family and partners, some of them being in the academic sector and living in other countries. Previous work has analyzed how the institutionalization of transnational academic mobility affects the work-life balance of dual career couples (Sallee and Lewis, 2020), particularly women (Tzanakou, 2017). However, with the exception of some work on the environmental footprint of international students (Arsenault et al., 2019), there are no estimates of the carbon footprint of the internationalization of research activities. In that sense, the results shown here highlight the importance of a hidden cost of researchers' international mobility in terms of carbon emissions.

Given the high emissions associated with travel, commuting and the use of digital technologies represent a low share of the project's carbon footprint. However, including these two categories in carbon footprint calculations remains important for two reasons. First, carbon emissions matter in absolute terms, so efforts to reduce emissions in these two categories also need to be considered. Second, the generalization of teleworking and the consequent increase in the use of digital technologies (Obringer et al., 2021) might result in increasing emissions if measures are not taken to minimize their impact, especially in regions where energy is still highly reliant on fossil fuels.

4.1. *Potential impacts associated with the introduction of carbon reduction measures*

The introduction of measures aiming to reduce carbon emissions requires explicit consideration of the potential spillover effects of such measures across a range of aspects (Morrison-Saunders and Pope, 2013). In a decision-oriented context, examining such impacts is important to discern acceptable from unacceptable rules and to avoid unintended negative impacts. Based on related literature, this section discusses potential impacts of the measures proposed in the two scenarios in terms of a) CO_2 emissions, b) academic outputs, c) economic costs, and d) researcher's work-life balance.

Impacts on CO_2 emissions: The measures proposed under the two scenarios are exclusively oriented to reduce carbon emissions and the calculations suggest that these measures would, indeed, achieve that goal to one extent or another. It is important to note, however, that the calculations do not consider potential rebound effects, or reductions in expected gains because of behavioural changes (Hook et al., 2020; O'Brien and Yazdani Aliabadi, 2020). For example, the scenarios propose teleworking to reduce carbon emissions associated with commuting. However, recent work shows that while teleworking reduces commuting carbon emissions (Brömmelhaus et al., 2020; Emre and De Spiegeleare, 2019), it might also increase home-energy use and non-work travel (e.g., driving kids to school if the possibility of teleworking resulted in family relocation). In other words, in an economy-wide energy context, the gains from reduced commuting might be outweighed by its rebound effects (Hook et al., 2020; O'Brien and Yazdani Aliabadi, 2020). Rebound effects could also be expected if, for example, researchers' increase personal travel to compensate the reduction of research-related travel. While the rebound effects of carbon reduction measures are largely unpredictable and, therefore, difficult to estimate, potential behavioral changes derived from the implementation of carbon reduction measures should be acknowledged and discussed considering an economy-wide energy context.

Impact on academic outputs: Carbon reduction measures might impact academic outputs both in terms of researchers' career and in terms of project's results. In relation to researchers' career, although previous work suggests that air travel does not correlate with individual academic productivity (Wynes et al., 2019), international mobility continues to be highly valued in the academic environment and largely considered as a token of success and prestige (Glover et al., 2018; Grantham, 2018; Wynes et al., 2019). Restricting travel and international mobility might have different impacts at different career stages or for different activities. For example, reducing travel might have a lower academic impact for a senior than for a junior researcher or than for a researcher in a developing country with little opportunities to travel internationally. Similarly, renouncing to travel to a conference might have lower impact than renouncing to travel for fieldwork and data collection. Importantly, the measures proposed to reduce carbon emissions could also have positive impacts in terms of researchers' career. For example, the generalization of online events might lower participation barriers, particularly for scientists with family responsibilities, scientists with little budget to travel, or scientists working in remote regions, thus potentially benefiting them (Foramitti et al., 2021; Klöwer et al., 2020).

Impacts on project's academic outputs are difficult to predict. In principle, the application of measures under the reduced emissions scenario might not affect neither the undertaking nor the quality of activities, for which they might not have large academic impacts. In that sense, despite its many challenges, the Covid-19 pandemic crisis has shown that –indeed- many academic activities can be conducted remotely, resulting in the reduction of global CO_2 emissions (Le Quéré et al., 2020). For example, with the Covid-19 crisis, teleworking and virtual meetings have become more common and many conferences have been celebrated online without apparent side effect impacts on scientific outputs and with a consequent reduction in carbon emissions (Foramitti et al., 2021). However, the application of the measures under the net-zero emissions scenario would have potentially had a more visible impact in project's outputs. In particular, the drastic limitation of travel would had made impossible for researchers to travel to the field to test the methods, which would have resulted in a less robust methodological design. Similarly, training partners through a virtual event would have led to lower personal involvement and to a lower commitment to project objectives.

The measure proposed to reduce emissions associated to international mobility, i.e., recruiting a European or Spanish vs. an international team, also requires special consideration. Under current conditions, restricting recruitment to European/Spanish nationals can, in fact, have important impacts on researcher's careers and project's academic outputs. If applied at a large scale, such restriction might have a disproportionally negative impact on researchers from countries with weak scientific infrastructure, as these researchers would have limited chances to develop a scientific career. Overall, this would not only disproportionally reduce opportunities for some scientists (based on their country of origin), but also exacerbate existing inequalities in science (Xie, 2014). Additionally, having a strictly European or Spanish team might narrow the diversity of perspectives and reduce the legitimacy of the project in international spheres. This is particularly important for projects - like the one analyzed here – that are essentially based on collaborations with scientists and institutions from multiple countries.

Economic impact: Measures taken to reduce carbon emissions might also have different impacts on the economic costs of the project, depending on the scenario and the measure considered. Some measures oriented to promote responsible travel might result in additional expenses, as direct flights or speed trains can be more expensive. However, in general, travel reductions (i.e., substituting traveling for remote participation in scientific activities, or conducting decentralizing training to avoid intercontinental flights) might result in monetary savings, that could potentially be reoriented to mitigate some of the other impacts of travel reduction measures.

Impact on researchers' work-life balance: Measures taken to reduce carbon emissions might also impact researchers' work-life balance. For example, rules for responsible travel might have both positive and negative impacts on researchers' personal lives. On the positive side, as researchers travel quite frequently, reducing commuting and long-distance travel (e.g., through attending meetings remotely) might increase researchers' wellbeing and improve their work-life balance (Emre and De Spiegeleare, 2019). On the negative side, some of the measures to reduce carbon emissions associated with travel (e.g., traveling by train) might prolong time away from home, thus producing the opposite effect. Similarly, while allowing teleworking might contribute to increase researchers' wellbeing (Emre and De Spiegeleare, 2019), the generalization of teleworking can result in negative effects by disconnecting the researcher from peers and by shifting work-related costs (e.g., home-office energy) to researchers.

Together, the points discussed above seem to suggest that the implementation of the measures to reduce carbon emissions might have spill over effects on academic outputs, economic costs, and researchers' work-life balance. While the magnitude and direction of these impacts is difficult to quantify, the careful examination of impacts is important to discern rules acceptability and to avoid unintended consequences of decisions oriented to reduce carbon emissions.

4.2. Voluntary action: the major bottleneck to decarbonize research and recommendations for action

This last section emphasizes a paradox in the findings of this study. The discussion above suggests that the reduced emissions scenario would have help to align the project with the EU pledge on the Paris Agreement to reduce emissions by "at least 40%" by 2030, without major impacts to the project's academic output. The paradox is then, why LICCI core team members, a group of researchers legitimately concerned with climate change impacts, did not put in place –at least-some of these measures to reduce carbon emissions? Answers to this question can be found in examining the major bottleneck to decarbonize research, i.e., reliance on voluntary action, and outline some measures that might help to overcome it.

A major bottleneck in the adoption of measures to reduce academia's carbon footprint is that, to date, the adoption of such measures rely on voluntary action by researchers –or institutions-who often face private costs in adopting carbon reduction measures (e.g., Jean and Wymant, 2019; Kjellman, 2019; Klöwer et al., 2020). For example, young researchers renouncing to international mobility to reduce their carbon emissions might also reduce their career opportunities, as international mobility continue to be a pre-requisite of many academic jobs. Similarly, researchers aiming to adopt carbon reduction measures might face the increased private costs of dealing with administration, as most funding agencies and research institutions have complex and rigid management systems not ready for the implementation of some of the measures proposed. Administrative barriers that increase the private costs faced by researchers to decarbonize research activities range from academic institutions' internal organization rules encouraging cheap travel, to the fact that most funding agencies do not recognize offsetting carbon emissions as eligible costs. Thus, in answer to the paradox presented above, one could argue that since many of the already proposed measures to decarbonize the academic sector involve trade-offs between events that occur at different time (e.g., traveling now to make academic connections vs. future climate impacts) and social scales (e.g., own career vs. climate change from aggregated behaviour), it is not surprising that relying in voluntary action results in limited self-sacrifice.

To avoid the undesirable scenario of high carbon emissions of research projects, governments and funding agencies need to assure harmonization and compliance of rules to decarbonize research. Actions in this direction could include the development of normative standards of scientific research practice that encourage, value or even enforce the reduction of carbon emissions. These normative standards need to be encouraged from the project design phase and avoid reliance on individual or institutional voluntary action. For example, funding agencies could impose carbon budgets, requiring an estimation of the carbon to be emitted by proposed research activities and a justification of unavoidable emissions – while taking into consideration not only project's needs, but also countries' circumstances and applicant's career stages. In the particular example examined here, including such considerations during the project's design (for example by requiring that proposals include a carbon footprint assessment or a carbon budget) would have resulted in a considerable reduction in emissions. On their side, research institutions could put in place a framework that regulate international mobility and responsible travel policies that consider minimizing carbon emissions, thus moving the decarbonization of the research sector away from voluntary action. Such framework should consider not only responsible travel, but also measures referring to teleworking, encouraging dual career services (Tzanakou, 2017), or promoting flexible arrangements related with working from abroad. To increase the legitimacy of the process, defining the specifics of these rules and regulations would require a wide debate between the scientific community and funding agencies and research institutions. Such measures should then be enabled by allocating personnel and resources that would allow their operationalization.

Asking for institutional changes and for the shift in research standards would likely meet resistance. However, the widespread work and travel habit discontinuity imposed by the Covid-19 pandemic has also brought examples of alternative work arrangements and opened pathways to change the way science is done (Haggar et al., 2019). The creation and enforcement of institutional frameworks that encourage and require researchers to minimize the carbon impact of their activities should be the first important step to decarbonize research, and governments and other funding bodies have to take the lead in promoting structural changes.

CRediT authorship contribution statement

Victoria Reyes-García: Conceptualization, Methodology, Supervision, Writing – review & editing. **Lorena Graf:** Data curation, Writing – original draft. **André B. Junqueira:** Methodology, Formal analysis, Visualization. **Cristina Madrid:** Data curation, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Research leading to this paper has received funding from the European Research Council under an ERC Consolidator Grant (FP7-771056-LICCI). We thank researchers of LICCI project for their help and comments during this work. Research results were presented at the "ICTA-UAB Virtual Conference 2020 on low-Carbon Lifestyle Changes" (https://lifestyle-changes.org) and have been discussed with members of the Laboratory of Analysis of Social-Ecological systems under Globalization (LASEG) research group and members of the "Responsible travel" committee at the Institute of Environmental Science and Technology of the Autonomous University of Barcelona (ICTA-UAB). We thank inputs from all these fora. Thanks also go to E. Poncela for compiling the data, and to A. Schlingmann and S. Alvarez for help with figures. This work contributes to the "María de Maeztu" Programme for Units of Excellence in R&D (MdM-2019-0940).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.133174.

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