RESEARCH ARTICLE

A transition support system to build decarbonization scenarios in the academic community

Nicolas Gratiot[1]*, Jérémie Klein[2], Marceau Challet[2], Olivier Dangles[3], Serge Janicot[4], Miriam Candelas[5], Géraldine Sarret[6], Géremy Panthou[1], Benoît Hingray[1], Nicolas Champollion[1], Julien Montillaud[7], Pascal Bellemain[8], Odin Marc[9], Cédric-Stéphane Bationo[10], Loïs Monnier[9], Laure Laffont[9], Marie-Alice Foujols[11], Véronique Riffault[12], Liselotte Tinel[12], Emmanuel Mignot[13], Nathalie Philippon[1], Alain Dezetter[14], Alexandre Caron[15], Guillaume Piton[16], Aurélie Verney-Carron[17], Anne Delaballe[18], Nelly Bardet[19], Florence Nozay-Maurice[20], Anne-Sophie Loison[21], Franck Delbart[22], Sandrine Anquetin[1], Françoise Immel[23], Christophe Baehr[24], Fabien Malbet[25], Céline Berni[26], Laurence Delattre[27], Vincent Echevin[4], Elodie Petitdidier[28], Olivier Aumont[4], Florence Michau[29], Nicolas Bijon[30], Jean-Philippe Vidal[26], Sébastien Pinel[31], Océane Biabiany[32], Cathy Grevesse[33], Louise Mimeau[16], Anne Biarnès[34], Charlotte Récapet[35], Morgane Costes-Thiré[36], Mariline Poupaud[15], Maialen Barret[37], Marie Bonnin[38], Virginie Mournetas[39], Bernard Tourancheau[29], Bertrand Goldman[40], Marie Paule Bonnet[41], Isabelle Michaud Soret[42]

1 Institute of Environmental Geosciences (IGE), Grenoble Alps University (UGA), French National Centre for Scientific Research (CNRS), Grenoble Institute of Technology (Grenoble-INP), French Research Institute for Development (IRD), Saint-Martin d'Hères, France, **2** School of engineering in Physics, Applied Physics, Electronics & Materials Science, Grenoble Alps University (UGA), Grenoble Institute of Technology (Grenoble-INP), Grenoble, France, **3** Center in Ecology and Evolutionary Ecology (CEFE), University of Montpellier (UM), French National Centre for Scientific Research (CNRS), Practical School of Advanced Studies (EPHE), French Research Institute for Development (IRD), Montpellier, France, **4** Laboratory of Oceanography and Climate: Experiments and Numerical Approaches (LOCEAN), Sorbonne University, French National Centre for Scientific Research (CNRS), French National Museum of Natural History, French Research Institute for Development (IRD), Paris, France, **5** Institute of Physiology, Czech Academy of Sciences (ASCR), Praha, Czechia, **6** Earth Sciences Institute (ISTerre), Grenoble Alps University (UGA), University Savoie Mont Blanc (USMB), French National Centre for Scientific Research (CNRS), French Research Institute for Development (IRD), French Institute of Science and Technology for Transport, Development and Networks (IFFSTAR), Grenoble, France, **7** Research unit "Universe, Time-frequency, Interfaces, Nanostructures, Atmosphere and environment, Molecules" (UTINAM), French National Centre for Scientific Research (CNRS), University Burgundy Franche-Comté, Besançon, France, **8** Grenoble Images Parole Signal Automatique (GIPSA-lab), Grenoble Alps University (UGA), French National Centre for Scientific Research (CNRS), Grenoble Institute of Technology (Grenoble-INP), Saint-Martin d'Hères, France, **9** Geosciences Environnement Toulouse (GET), French National Centre for Scientific Research (CNRS), French Research Institute for Development (IRD), French National Centre for Space Studies (CNES), Paul Sabatier University (UPS), Midi-Pyrénées Observatory (OMP), Toulouse, France, **10** Economic and Social Sciences of Health and Medical Information Processing (SESSTIM), institute of public health sciences (ISSPAM), Aix-Marseille University (AMU), French National Institute of Health and Medical Research (INSERM), French Research Institute for Development (IRD), Marseille, France, **11** Institute Pierre-Simon Laplace (IPSL), Sorbonne University, French National Centre for Scientific Research (CNRS), Paris, France, **12** Centre for Education, Research and Innovation in Energy Environment (CERI EE), IMT Nord Europe, Institut Mines-Télécom (IMT), University of Lille (UDL), Lille, France, **13** Fluid Mechanics and Acoustics Laboratory (LMFA), University of Lyon (UDL), National Institute for Applied Sciences of Lyon (INSA Lyon), Central School of Lyon (ECL), UCBL, French National Centre for Scientific Research (CNRS), Villeurbanne, France, **14** Research Unit "HydroSciences Montpellier" (HSM), University of Montpellier (UM), French Research Institute for Development (IRD), French National Centre for Scientific Research (CNRS), Montpellier, France, **15** Research Unit "Animals, Health, Territories, Risks and Ecosystems" (ASTRE), University of Montpellier (UM), Agricultural Research Centre for International Development (CIRAD), French National Research Institute for Agriculture, Food and Environment (INRAE), Montpellier, France, **16** Research Unit "Torrential Erosion, Snow & Avalanches" (ETNA), Grenoble Alps University (UGA), French

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National Research Institute for Agriculture, Food and Environment (INRAE), Grenoble, France, **17** Interuniversity Laboratory of Atmospheric Systems (LISA), Paris-East Créteil University (UPEC), Créteil, France, **18** UGA Design Factory, Grenoble Alps University (UGA), Saint-Martin d'Hères, France, **19** Department of distance education, French Research Institute for Development (IRD), Marseille, France, **20** French Research Institute for Development (IRD), Marseille, France, **21** HEMiSF4iRE Design School, Catholic University of Lille, Lille, France, **22** French Polar Institute (IPEV), University of Western Brittany (UBO), Brest, France, **23** Research unit "Chrono-environnement", French National Centre for Scientific Research (CNRS), University Burgundy Franche-Comté, Besançon, France, **24** National Centre for Meteorological Research (CNRM), French National Centre for Scientific Research (CNRS), Toulouse, France, **25** Planetology and Astrophysics Institute of Grenoble (IPAG), Grenoble Alps University (UGA), French National Centre for Scientific Research (CNRS), Grenoble, France, **26** Research Unit "RiverLy ", French National Research Institute for Agriculture, Food and Environment (INRAE), Villeurbanne, France, **27** Research unit "Lille Economics Management" (LEM), University of Lille (UDL), French National Centre for Scientific Research (CNRS), IESEG School of Management, Lille, France, **28** Research unit INTERTRYP, University of Montpellier (UM), French Research Institute for Development (IRD), Agricultural Research Centre for International Development (CIRAD), Montpellier, France, **29** Grenoble Informatics Laboratory (LIG), Grenoble Alps University (UGA), Saint-Martin d'Hères, France, **30** Research Unit "Recycling and Risk", Agricultural Research Centre for International Development (CIRAD), Montpellier, France, **31** Centre of Education and Research on Mediterranean Environments (CEFREM), University of Perpignan Via Domitia (UPVD), Perpignan, France, **32** Agroecology, genetics, and tropical livestock systems (ASSET), French National Research Institute for Agriculture, Food and Environment (INRAE), Petit-Bourg, France, **33** Office of the Director General in charge of Research and Strategy, Agricultural Research Centre for International Development (CIRAD), Montpellier, France, **34** Laboratory for the study of Soil-Agrosystem-Hydrosystem interactions (LISAH), University of Montpellier (UM), French National Research Institute for Agriculture, Food and Environment (INRAE), French Research Institute for Development (IRD), Institute Agro, Montpellier, France, **35** Behavioural Ecology and Fish Population Biology (ECOBIOP), University of Pau and the Adour Region (UPPA), Energy Environment Solutions (E2S), French National Research Institute for Agriculture, Food and Environment (INRAE), Saint-Pée-sur-Nivelle, France, **36** Genetics, Physiology and Livestock Systems (GenPhySE), French National Research Institute for Agriculture, Food and Environment (INRAE), University of Toulouse, ENVT, Toulouse INP, Castanet Tolosan, France, **37** Laboratory of functional ecology and environment (ECOLAB), French National Centre for Scientific Research (CNRS), Paul Sabatier University (UPS), Toulouse Institute of Technology (Toulouse-INP), Toulouse, France, **38** Laboratory of Marine Environmental Sciences (LEMAR), French Research Institute for Development (IRD), French National Centre for Scientific Research (CNRS), French Research Institute for Exploitation of the Sea (IFREMER), University of Western Brittany (UBO), 29280 Plouzané, France, **39** ADLIN Science, Evry, France, **40** Max-Planck-Institut für Astronomie, Heidelberg, Germany, **41** Research unit Espace-DEV, University of Montpellier (UM), Institute of Research for Development, Guyane University, University of Reunion, Montpellier, France, **42** Chemistry and Biology of Metals laboratory (LCBM), Interdisciplinary Research Institute of Grenoble (IRIG), University Grenoble Alps (UGA), French National Centre for Scientific Research (CNRS), Alternative and Atomic Energies Agency (CEA), Grenoble, France

* nicolas.gratiot@ird.fr

Abstract

A growing portion of scientists realises the need to not only alert about climate change, but also change their professional practices. A range of tools have emerged to promote more sustainable activities, yet many scientists struggle to go beyond simple awareness-raising to create concrete transition actions. Here we propose a game-based transition support system *MaTerre180'*, which has been designed to build scenarios of greenhouse gas (GHG) emission reductions in the academic community. After providing a common scientific background about the context (global warming issue, its causes and consequences) and setting up a challenge (50% reduction of carbon budget by 2030), the participants belonging to the academic community and its governance bodies immerse themselves into fictional characters, to simulate the behaviour of real research groups. The game has been deployed during the year 2021, with six hundred participants from nine countries and 50 cities. Results explore clear pathways for GHG reductions between 25 and 60%, and a median reduction of 46%. The alternatives allowing the greatest reduction are video communication tools (36%), followed by mutualization of professional activities and voluntary cancellation or reduction, that represent 22 and 14% of reduction, respectively. The remaining 28% of reduction consists of transport alternative, relocation of professional activities, extended duration of some travels, etc. In addition, the analyses pointed out the importance of the guided negotiation phase to bring out some alternatives such as relocation, local partners and computing optimization. An added value of this transition support system is that the information it collects (anonymously) will be used to answer pressing research questions in climate change science and environmental psychology regarding the use of serious games for promoting changes in attitudes and behaviours towards sustainability, and including broader questions on how network structures influence "climate behaviour", knowledge and the governance of the commons.

Modestly, *MaTerre180'* offers an innovative game-based transition support system to build scenarios of greenhouse gas (GHG) emission reductions in the academic community. It is not simply a question of moving tokens on a virtual gameboard and a playful adjustment of practices, but rather a question of brainstorming about possible and desirable ways of remodelling research and teaching communities and embracing a new paradigm. After tens of workshops, our results show clear pathways for reaching up to 50% GHG reductions and stress the importance of guided negotiations to bring out alternatives to carbonized activities. This first attempt reinforces our belief that scientific engagement is at the heart of the international development agenda and a key approach to tear down the institutional barriers that inhibit the transformation needed to achieve a more sustainable society.

1. Author summary

For the last centuries, humans have upscaled their socio-economic structures and globalized their interactions; and these unprecedented developments have been largely driven by our capacity to extract energy and resources from the Earth. In developed countries, people live in a carbonized world, where almost unlimited access to fossil resources and derived goods has become the norm. Generations after generations, homo sapiens switched and installed themselves in the ideology of a no limit planet. For some decades now, scientists have warned about the inadequacy between this commonly shared belief and the physical and biogeochemical limits. In simple words, the "carbonized sapiens" now know the threats but miss guidelines to reinvent themselves.

2. Introduction

Since 1972, Meadows et al. (1972[1]) were probably the first to point out some major problems faced by humankind and how the exponential growth of population, food production, industrialization, pollution, and consumption of non-renewable natural resources, would ultimately lead to an overshoot of the Earth's capacity. New concepts emerged later such as planetary boundaries (Rockstrom et al., 2009[2]), which were defined as nine parameters whose transgressions could lead to catastrophic consequences for humankind, due to the existence of thresholds triggering abrupt changes. Carbon footprint–as addressed in this role-playing game–is only one measure of our impact on the planet, among others; but it translates our use of fossil fuels in various sectors and its decrease would certainly affect many of the current negative feedbacks of anthropogenic activities, such as loss of biodiversity and shortage of critical resources.

Since the Paris agreement on climate change in 2015, and the Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5˚C (IPCC, 2018[3]), 191 states have committed to set ever more stringent policies of greenhouse gas (GHG) reduction (UNFCCC report, 2021[4]). In this context, the European Union has set the target of achieving, at least, a 55% reduction in GHG by 2030, compared to 1990. On July 8 2021, the European Central Bank took a historic step by announcing, for the first time, the integration of climate change into its monetary policy. Earlier in 2021, the International Energy Agency called on governments to ensure that their economic recovery plans focus on clean energy investments in order to create the conditions for a sustainable recovery and long-term structural decline in carbon emissions (IEA report, 2021[5]).

At the global scale, a systemic change through moderate to low GHG emissions can only be reached if both individuals and communities endorse a dual responsibility to inform policy makers and citizens about the threatening situation for humans and life on Earth. It requires action to promote a form of frugality (Vaden et al., 2020[6]) and embody a socio-ecological transition toward low carbon societies (IPCC, 2018[3]; Otto et al., 2020[7]). In France, this dual responsibility is unavoidable since individual actions, such as commitments and financial investments, can at best reach a 45% reduction of GHG emission (Dugast et al., 2019[8]).

Changing the individual and collective behaviors of society is quite challenging but is key in implementing efficient public policies. Behavioral science can help in designing tools that promote sustainable behaviors (OCDE, 2017[9]). Besides, serious games (or learning games) have now been developed for decades in various fields, with a common feature which is to not be targeting mere entertainment. These games allow players to develop problem-solving skills in a real-world context, as well as engagement and responsibility (Cheng et al., 2020[10]). In a game-based approach, participants are required to adopt roles with possibly competing interests and various perspectives depending on the consequences of the issue on their character(s), which foster multiple opinions and collaborative argument to reach a common goal (Doerr-Stevens et al., 2011[11]; Guigon et al., 2021[12]). Role-playing games (RPG) have already been used and their efficacy assessed for various environmental issues. Salvini et al. (2016[13]) explored their use to promote sustainable land-use agricultural practices with Brazilian farmers. Besides technical knowledge, they observed socio-institutional learning and engagement in collective action for one of the three groups of farmers involved. Meinzen-Dick et al. (2018 [14]) report of games used in a pilot study to improve groundwater resource management in Andhra Pradesh, India. Communities where the games were played were more prone to adopt water registers and rules to govern groundwater, compared to other communities which did not follow the games. In the SECOLOZ game, the impact on ecosystem services as a function of three different farming practices in Lozère, France, has been facilitated between local stakeholders (Moreau et al., 2019[15]). Agusdinata and Lukosh (2019[16]) designed the HomeRUN RPG to decrease the amount of GHG emissions arising from the consumption of food, energy, and water resources at the household level.

GHG emissions of academic activities can no longer be ignored. As highlighted by the IPCC (2018[1]), limiting global warming to 1.5˚C or even 2˚C requires a drastic and rapid reduction of GHG emissions that must concern all sectors of activity, particularly in developed countries (Mahlstein et al., 2011[17]). In this respect, the academic world is not an exception (Attari et al., 2016[18]). Besides, cognitive dissonance is high in all spheres and perhaps even more within the academic world, which can no longer afford to only raise awareness and alarm about the upcoming crisis, but must act as pioneers and embody changes (Schrems and Upham, 2020[19]; Whitmarsh et al., 2020[20]).

Defining a robust strategy of emissions reduction implies, firstly, to accurately monitor GHG emissions. In the academic sector, a group of French researchers, named Labos1point5 (https://labos1point5.org/), developed an open-source tool called 'GES1point5' to help research units calculate their carbon footprint (Mariette et al., 2022[21]). Monitoring is a first step but it is insufficient to lead to in-depth changes of our professional behaviour (Hulme, 2020[22]). Yet, a growing portion of the scientific community realises the need to not only alert but also change their professional practices. Moreover, according to Attari et al. (2016 [18]), the credibility of scientists and of their warnings is increased when they behave in a non-dissonant manner. According to a study carried out among 6000 people (Labos 1point5, 2020 [23]), 88% of French researchers "completely agree" or "somewhat agree" that the climate emergency requires profound changes in their practices; however, the structural and functional framework of the academic sector and the evaluation of academic performances do not favour the emergence of sustainable trajectories. On the contrary, it largely promotes researchers' behaviours that lead to high carbon pathways (e.g. international travel, promotion of international network, use of high-technology and unique scientific instruments).

Nowadays, whether for conferences, field surveys, highly specific instrument experiments, thesis defences or project meetings, the emissions linked to researchers' mobilities are an important (and sometimes predominant) contribution of a laboratory GHG footprint (Whitmarsh et al., 2020[20]). In addition, travel practices are inequitably distributed among individuals, reaching per instance 10.8 tCO_2e (i.e. where all GHG have been converted to an equivalent CO_2 greenhouse forcing) per capita on a yearly average for a professor at the University of Montreal (Arsenault et al., 2019 [24]) and 7.5 tCO_2e at the University of British Columbia (Wynes et al., 2019 [25]). For both locations in Canada, this sole activity corresponds to a vast proportion of what the average person from that country emits during a year (19.4 t CO_2e/capita in 2019) (Canada, 2021[26]), which is far away from Canada's commitment to reach net-zero emissions by 2050. The use of aircraft is a predominant source of GHG emissions and according to some authors (Wynes et al., 2019[25]), it would not necessarily bring a clear benefit in terms of career development and enhancement of professional relations.

A range of tools, of varying degrees of entertainment and constraint, are gradually emerging, but many of them struggle to go beyond simple awareness-raising to create concrete transition actions (Galeote, et al., 2021[27]). In France, as in many other countries, a growing number of researchers organize themselves to change their work habits and embrace more sustainable practices; a trend that was accelerated due to the COVID pandemic crisis and the increase of video communications. Some alternatives should be in place to enlarge the scientific community involved, but also to provide an overall vision of possible pathways of GHG emission reductions. Current approaches include incitative measures (carbon tax, ecological money), regulatory measures (carbon quotas, green charter, carbon offsetting) and several gamification approaches, such as for France: (i) The Climate Fresk, a 3-hour collaborative workshop to understand the scientific bases of climate change and start taking action (https://climatefresk.org/). (ii) ClimaTicTac, a French collaborative strategy board game for players above 9 years old developed by French CNRS and CEA scientists (https://climatictac.ipsl.fr/). (iii) 2 Tonnes, a 3-hour workshop to find solutions to reach the desirable footprint of 2 tons equivalent CO_2 per year per person, an objective to be reached by 2050 to respect the commitments of the Paris Agreement, that is to say to keep the increase in global temperature at a level below 2 degrees (https://en.2tonnes.org/atelier), and (iv) Carbon Lean, a card game for players above 8 years old, to discover their own carbon footprint and try to minimize it (https://www.carbon-lean.com/). The latter can take the form of serious games, which simulate multi-actor systems for tackling the complexity of environmental issues and their interplay with many other domains (Oliver, 2016[28]).

In the context of climate change, digital serious games have been used for almost forty years (Robinson and Ausubel, 1983[29]). In their literature review, comprising tens of gamified approaches, Galeote et al. (2021[27]) showed that serious games stimulate cognitive engagement, affect the perception of climate change-related topics and behavioural engagement with others, by combining learning and entertainment. Serious games create a sphere of thinking around a complex topic while maintaining a playful atmosphere. As players, participants then embody positions or roles that are not necessarily their own, and relate more easily with issues that do not concern them directly or by which they did not think they were concerned. Moreover, serious games generate dynamics of opposition or cooperation involving the players' emotions to immerse them further in their character and promote the players' empathy towards roles different from their real-life conditions (Wiemeyer et al, 2016[30]). They favour moments that create links and encourage sincere exchanges. According to Gee (2008) [31], serious games need to be moderately funny or "pleasantly frustrating" to be serious enough. This characteristic makes the adaptation of serious games on the theme of climate change or socio-ecological concerns perfectly appropriate. Indeed, these topics are surely some major issues of our time, and at the same time the most postponed ones. In this context, there are more and more serious games being set up to raise awareness on these issues among the various social, political and economic stakeholders (Onencan et al., 2016[32]; Terti et al., 2019[33]; Undorf et al., 2020[34]).

In this perspective, we developed *MaTerre180'* (i.e. *MyEarth180'*), a transition support system including a game-based participatory tool, that aims at raising awareness regarding the carbon footprint of the academic world, and identifying ways of reductions through social interactions. *MaTerre180'* particularly focuses on the predominant proportion of air travel in the academic carbon footprint, but also includes other means of transportation (train, car or boat for oceanographic surveys) as well as additional sources of emissions such as numerical simulations and the access to highly technologic and unique scientific instruments (e.g., particle collider). *MaTerre180'* goes beyond the mere framework of learning by first identifying solutions, then embracing action and bringing to light concrete solutions to reduce academic GHG emissions.

After a general description of the timeline, materials and methods, results focus on the analysis of the eighty-five game-based phases played to date. These games have been analysed in order to discuss the applicability of the suggested solutions for GHG emission reduction within the academic world. In particular, it has been possible to assess the robustness of the proposed alternatives through indicators of their spontaneity and popularity. Finally, we questioned the indicators used to measure academic performance and their consistency with the GHG emission reduction objectives in order to open discussions on the possible and most effective ways to implement the proposed strategies.

3. Material and methods

a. Ethics statement

All aspects of the experimental procedures were reviewed and approved by the "scientific board" of the French National Research Institute for Sustainable Development (IRD-France, approval n° D2S-2022-002). All participants gave consent to the facilitators prior to their participation: once the online session was opened, the facilitator of each table asked each participant of the workshop for the right to record the videos as a source of raw data for further non-profit research. When the agreement was not obtained for all individual participants, the session was not recorded and the corresponding table was not considered for further analysis. When the agreement was obtained the session was recorded and the facilitator notified it by signing a letter agreement. We do remind that each participant role-play two fictive characters; no personal information on individuals were collected, only on the actions of their fictive characters during the game.

b. *MaTerre180'*, a game-based participatory tool

MaTerre180' is a Transition Support System organised in four distinct phases, through which an academic institute/group will seek to change the organisation of its academic work to reach a target GHG emission reduction. Fig 1 summarises the timeline. The deployment of *MaTerre180'* lasts 180 minutes (+ 30 minutes debrief time). It runs over two half-days, to help the participants gain sufficient introspection and encourage their cognitive engagement. As an adaptation to the COVID pandemic, *MaTerre180'* has been designed to be deployed online, which proved to be particularly useful for the massification and the digitization of this game-based approach.

In this paper, the analysis focuses on the role-playing phase of the *MaTerre180'* workshop (phase 3 in Fig 1).

Each *MaTerre180'* individual workshop aims to gather a facilitator, six participants, one of them playing the role of team leader, and an advisor.

Phase 1: The awareness-raising phase

This first phase intends to build a common background on the topic among participants, and to offer them the opportunity to know each other, a key prerequisite before the further discussions and negotiations. Phase 1 is based on a set of documents containing general ecological statements: the crossing of four of the nine global limits (Rockstrom et al. 2009[2]; Steffen et al. 2015[35]) and the theory of the doughnut economy (Raworth, 2012[36]). Then follows a more specific section on climate change, with an overview on global temperatures (https://showyourstripes.info/) and their possible evolution in France (Bador et al, 2017[37]). The rest of the awareness-raising documents deal more specifically with the academic world, presenting the carbon footprint of some French research groups (IGE, ISTerre and LOCEAN), the impact of some research activities at the individual scale (Berthoud et al., 2019[38]) and the results of

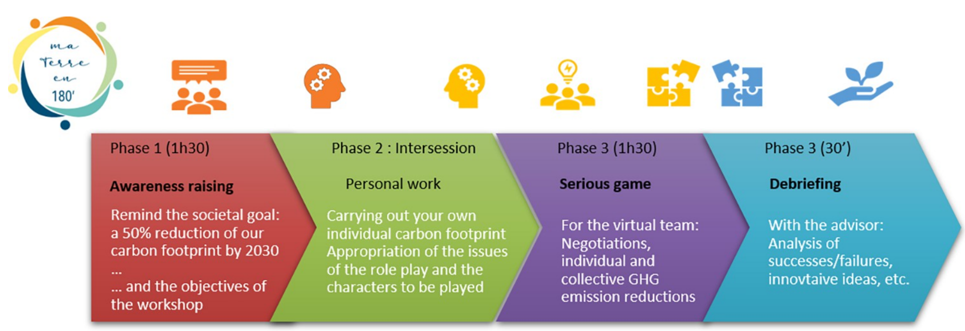

Fig 1. Timeline of the *MaTerre180'* Transition Support System. Each workshop is composed of four phases to raise awareness (phase 1), make some introspection (phase 2), participate in a role-playing serious game (phase 3) and debrief about results and postures (phase 4).

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the survey on academic practices and awareness "*Les personnels de la recherche face au changement climatique*" conducted by Labos 1point5 (Labos 1point5, 2020[23]). Emerging initiatives in some French research groups are then presented. The awareness-raising phase ends with a debrief time for sharing feelings, reactions, personal experiences and opinions through discussions. The next phases of *MaTerre180'*, including the role-playing phase, are also introduced during this first 90-minute session.

Phase 2: The intersession phase

Participants are invited, in the few days between the two sessions, to compute their personal carbon footprint with an open access simulator (https://avenirclimatique.org/micmac/simulationCarbone.php). They also familiarise themselves with the two characters they will play during the role-playing (i.e. game-based) phase, each related to a technician, researcher or professor profiles (see below).

Phase 3: The role-playing phase

During the role-playing phase, five out of the six participants play the roles of two different characters resulting from a fictitious research group. The sixth participant takes on the role of team leader, which will be detailed hereafter.

At the time of the study, 12 virtual research teams, each composed of ten characters, were available to simulate groups working on various topics with distinct approaches (laboratory experiments, numerical simulations, field surveys. . .). Each of them has its own characteristics and has been inspired from a real research group. In particular, the starting emissions of each virtual research team was inspired from real research group emissions computed with the GES1point5 online tool, designed specifically for research groups (Mariette et al., 2022[21]). At that time, both in GES1point5 computation and in the *MaTerre180'* virtual teams, the GHG emissions associated with purchases of research groups (whether for services, scientific equipment or consumables) were not considered yet. With this limit, the diversity of emissions of the virtual teams is representative of real research groups, representing different topics, institute policy, or approaches. Given the wide diversity of the games, most participants could choose a familiar research environment, which they generally did.

Table 1 lists the different virtual teams considered here, the team's initial GHG footprint and some keywords related to the scientific topics addressed. Their full description is available at https://materre.osug.fr/-Les-jeux-.

Each participant chose two cards describing his/her fictive characters and their respective activities and emissions. The set of 10 characters per virtual team includes senior and junior permanent researchers, PhD and postdoc students, engineers, technical and administrative staff. The description includes their links with the other team members, their academic reputation and lastly, their "ecological awareness profile". There are five types of "ecological awareness profile", ranging from a person fully concerned about climate change and already involved in collective actions (profile "Time for actions"), to someone considering that his/her career and duties justify a high carbon footprint (profile "I make the difference"). A game facilitator is in charge of animating the game, and an advisor (ideally chosen outside of the academic community) brings his/her external vision on the discussions and comments on the final results of the negotiations. In total, eight people are involved during the role-playing phase: the game facilitator, five participants that embody the 10 characters, one participant acting as team leader and one advisor, which ensures rich and open-minded social interactions. In case of registered participants not showing-up during the role-playing phase (or unable to attend), the game can be played with down to four participants (instead of six), with some

Table 1. List of the 12 virtual teams with their characteristics.

Name of the virtual team	Initial GHG footprint (sum in tCO_2e/year for ten characters)	Topics and keywords
Climatology	42.0	Climate change, local field studies, glaciers, snow science
Geophysics	62.0	Earthquakes and volcanoes, near and far field studies, databases, modelling
Earth Dynamics	43.5	Near and far field studies, geochemistry, partnerships with southern countries
Environment	48.0	Environmental sciences, geochemistry, mineralogy, unique instrument, near and far field studies
International Joint Laboratory	78.0	International laboratory, partnerships with southern countries (e.g. in South-eastern Asia), oceanography campaigns, numerical modelling
Society and environment	68.0	Sociology, anthropology, ecology, near and far field studies, collaborations with Southern partners
Ocean & Climate	70.0	Oceanography, high sea missions, high performance computing
Computer science (Informatics)	58.0	Parallel programming, artificial intelligence, image processing
Water Resources	63.0	Hydrology, critical zone, field studies (e.g. in Patagonia), with strong partnership with European partners (e.g. France and Germany)
Development & Environment	53.0	Near and far field studies
Air quality	61.0	Geochemistry, near and far field studies, biological and chemical analysis
Technology & transition	63.0	Automation, signal processing, control

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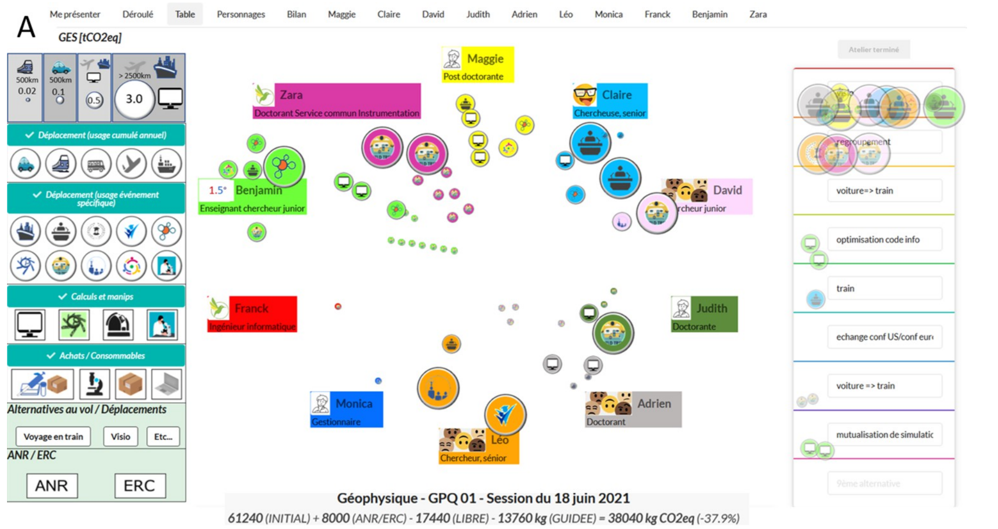
participants playing up to three characters and the team leader. For each virtual team, a virtual board is initially set with tokens representing the individual emitting activities of the 10 characters (see Fig 2A and Fig 2B). The surface area of the tokens is proportional to the GHG emission (Table 2) and labelled with a specific icon that symbolises the corresponding activity. The activities considered in the different virtual teams are listed in Fig 2B. They will be further referred to as "emission motives".

After 25 minutes of introduction and presentation of the board, characters and tokens, the strictly speaking role-playing phase takes place in three sub-phases: a free negotiation phase (20 min), a phase of publication of results of research funding applications (about 10min), and a guided negotiation phase (25 min). The remaining 10 minutes of phase 3 are dedicated to short debriefs by the advisor that will be extended in phase 4. The objective for the team during the negotiation phases is to perform their research while reducing the carbon footprint of their virtual team to a given target of fifty percent (50%).

During the "free negotiation" sub-phase, the virtual characters played by the participants discuss how to reduce by half the GHG footprint of their virtual research team. Each decision leads to an action: the game facilitator moves tokens on the virtual play mat, in or out of the game board and writes down the suggested alternatives through the digital interface (Fig 2A). Tokens can be substituted by others of smaller sizes, for instance if an intra continental (or domestic) travel by plane is substituted by a train journey. All proposed alternatives are eligible as long as they are accepted by the game facilitator, and co-opted by the participants and the advisor. The free negotiation phase ends by a short debriefing (5–10 minutes) during which the mid-term GHG footprint is presented by the advisor. The advisor also comments on the

A



B

Emission Motives / Scientific activity	Description	Icon
Conference	Travel to a conference or workshop	
Jury	Travel to be part of a jury (thesis, accreditation to supervise research, recruitment)	
Institutional meeting	Travel related to meetings in the field of research organisation	
Project meeting	Travel related to the setting up of projects and their implementation	
Field trip	Travel to acquire field data on a specific area	
Instrument	Travel and use of (very) high technology and unique scientific instruments (e.g. particle collider)	
Expertise	Travel related to consultancy for a state, an NGO, etc.	
Training, capacity building	Travel for teaching, capacity building and summer school etc.	
Oceanographic campaign	Campaign at deep-sea or coast for measurements	
Computing	Modelling using high performance computing facilities	

Fig 2. A. Digital interface used during the role-play phase. Example for the geophysics research team. The upper left-hand panel is the bank of tokens, the lower left-hand panel is the project's related tokens, the right hand panel is the area for low carbon alternatives. All research teams' interfaces are freely available from http://51.178.55.78/MT180/mt180.htm (the digital interface is coded in javascript). **B. Emission motives considered in the 12 virtual teams**.

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negotiations, shares his/her feelings and motivates the team to go beyond the efforts already undertaken.

The funding application sub-phase then begins. Before the free negotiations sub-phase, the characters were given the possibility to apply for French (French National Research Agency, ANR) or European (European Research Council, ERC) research funds. Each application has a

Table 2. Token sizes, related CO_2e emissions and corresponding characteristics of emission sources considered so far (Mariette et al., 2022[21]). Details on tokens can be found in appendix A.

Token Size	CO_2e emissions (in kg)	Characteristics of emission sources
Small	20	500 km journey by train
Medium	100	500 km journey by car 2500 km journey by train
Large	500	Short and medium-haul journey by plane 300,000 hours of CPU calculation 1 day of coastal ship mission
X-Large	3000	Long-haul journey by plane 1,800,000 hours of CPU calculation 3 days of high-sea ship mission

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⅙ probability of being awarded, close to the current real-life situation in France. Handling such projects implies additional travels that were estimated at 4.0 and 8.0 tCO_2e per year for French and European projects, respectively. During the research funding application sub-phase, the results of the applications are published and presented by the facilitator. The success (or failure) of project application is determined by simply rolling a digital dice. Additional tokens are then granted to the successful characters for each awarded project and displayed on the playmat, so that the GHG footprint of the team is increased.

Thirdly, the "guided negotiation" sub-phase led by the team leader takes place. He/she manages the negotiation phase as a research group leader and is free to choose his/her management strategy (authoritarian, consensual, persuasive. . .). This guided negotiation phase is also timed and lasts 25 minutes. At the end of the three sub-phases, the final GHG footprint is presented and a debriefing period starts.

In *MaTerre180'* transition support system, the role-playing phase allows participants to put their own research activities and professional constraints into perspective. Working in groups stimulates context-specific abstraction and active experimentation (Morris, 2020[39]).

Phase 4: The debriefing phase

This last 30-minutes phase closes the workshop. During the debriefing phase, the advisor gives his/her opinion on the suggested alternatives, on the way the characters were played and on the highlights of the role-playing phase. The team, the facilitator and the advisor come back to the highlights, share their opinions on the game-based phase and discuss the relevance and robustness of the proposals made to reduce the research team GHG emissions.

c. Database management

The role-playing can take place in a classical–i.e., physical–way around a table with all the material previously prepared (game board, character cards, tokens). The role-playing can also be performed online on an open access digital interface (Fig 2A and http://51.178.55.78/MT180/mt180.htm).

In the digital interface, game information is recorded automatically. Each action (e.g. removing a token) is associated with the name of the character to whom the token belongs, the motive for the removal of the token and its value in kg CO_2e. Some additional information concerns the phase of negotiation (free or guided) during which the action was played, and whether the token was attributed as a success to a research project application (French or European projects), the name of the alternative to which the token was moved, the reduction in kg CO_2e induced by this alternative and the time in seconds at which the token was last moved.

Each record is then concatenated in a database to group together all the games that have been played. Four meta information are thus added to identify individual games. Lastly the category of alternatives (see section on "alternative categorization" below) is specified for each of them. The database obtained is then cross-referenced with another one containing information specific to each virtual team as described in Table 1 (initial CO_2 balance, characters, psychological profiles, etc.) for further analysis. This makes it possible, for example, to analyse the results by table, by character, by sessions of the workshop, or by alternatives, in order to pay attention to specific points and decision processes.

d. Alternative categorization

As mentioned above, the suggested alternatives that emerged were expressed freely by each individual participant. They cover a rich and varied lexical field that had to be categorised in order to analyse them. These alternatives (translated in the appendix B from French to English) were classified in nine categories that were neither too general nor too specific in order to obtain a fair balance in the information provided. This categorization stems from reading the recorded games by some experts, which consequently involves a degree of subjectivity. Categories are described in Table 3.

e. Studied parameters

i. Trajectories of the different games, in terms of GHG footprint. For each workshop session, we look at the evolution of its GHG footprint according to the modifications (increase or reduction) of the absolute quantity of emissions Q_j^i in tCO_2e, where subscripts refer to each specific sub-phase *j* and superscripts to the individual workshop session number *i*.

Here, the potential emissions added or removed during the game, linked for instance to new funded projects or to behavioural changes, are taken into account in *Q* (e.g. using train instead of aircraft for a domestic journey both introduces several tokens of 20 $kgCO_2e$ for the train, the number depending on the distance, and removes the 500 $kgCO_2e$ token for the plane).

- *Initial time (j = 0)*: the initial carbon footprint of the virtual team is equal to the initial GHG emission assigned to each game (see Table 2):

$$CF_0^i = Q_0^i$$

- *After the free negotiation phase (j = FN)*: the new carbon footprint CF_{FN}^i is obtained by subtracting the emission reductions Q_{FN}^i that were proposed during the free negotiation phase

$$CF_{FN}^i = Q_0^i - Q_{FN}^i$$

Table 3. Description of the alternatives' categories identified so far.

Alternative category	Description
Video communication	All telecommunication activities between people, whether or not there is interaction. This includes video conferencing/communication, teleworking, e-learning such as Massive Open Online Courses (MOOCs), webinars, etc.
Mutualization	Pooling of a large diversity of activities. It includes the use of the terms: mutualization, merging, combination, pooling, association, grouping, etc.
Reduction/cancellation	Covers voluntary reduction of activity. It includes the words: cancellation, deletion, reduction, halving, etc.
Train / public transportation	Contains all plane or car trips replaced by train, long-distance buses and all types of public transportation.
Relocation	Brings the location of an activity at a closer distance, for example by preferring regional conferences or local field areas. This can be associated with the use of public transportation. The words used by participants can be: relocation, bringing closer, regional, local, etc.
Duration extension	Includes extension of the time spent on-site after travelling to avoid returning to the same place several times, or combination of several missions. Can sometimes be related to mutualization. This includes the terms: extension, expatriation, prolongation, long, duration, etc.
IT (Information Technology) optimization	Any solution that aims at reducing the energy consumption of intensive calculations, for example by making the codes less complex and/or better optimised. It covers the words: calculation, optimization, computing, data, etc.
Other	Includes some hardly classified alternatives and some original but infrequent ones. For example, the use of sailing boats for missions at sea, volunteer work or carbon offsetting inspired by Miyawaki forest restoration methods, etc.
Local Partners	Explicitly cite some local partners from foreign countries to mutualize some activities

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- *After results of ANR/ERC* project calls ($j = ANR/ERC$): depending whether research projects are granted or not, an emission surplus $Q^i_{ANR/ERC}$ can be added to the carbon footprint before the guided negotiation phase:

$$CF^i_{ANR/ERC} = Q^i_0 - Q^i_{FN} + Q^i_{ANR/ERC}$$

- *After the guided negotiation phase* ($j = GN = f$): the final (index f) carbon footprint is calculated by subtracting the additional emission reductions Q^i_{GN} suggested

$$CF^i_{GN} = CF^i_f = Q^i_0 - Q^i_{FN} + Q^i_{ANR/ERC} - Q^i_{GN}$$

- These absolute *CF* can be converted into a cumulative relative reduction *R*, for the corresponding phase *j*, using:

$$R^i_j = \frac{CF^i_j - CF^i_0}{CF^i_0}$$

ii. Alternatives and motives: Frequency, spontaneity and intensity of reductions. We also consider the amount of CO_2e avoided from the emission motive *m* to the alternative *a*. This allows us to describe in more detail pathways of GHG reductions for each emission motive and thus to deduce the total amount of GHG avoided by each alternative. It will also help to describe whether the emission motives are removed to alternatives or retained in the final GHG footprint of the team.

We define the frequency of a given alternative (see Table 3) as the ratio between the number of games that have used this alternative and the total number of games. For motives (Fig 3) a weighted calculation of the frequency of appearance is applied, since games present various initial types and numbers of activities.

Then, the spontaneity of the alternative (respectively motive) preferentially chosen (respectively removed) is defined as the minimum time before it first appears (respectively, is removed) in the game. This minimum time is then averaged over all games for each variable to deduce its average spontaneity.

Finally, we are interested in the GHG reduction intensity caused by an alternative or motive, i.e. the ratio between the total absolute reduction and the number of tokens moved. This allows us to estimate the ability of an alternative or the reduction motive to decrease the team's GHG footprint more or less efficiently. Thus, the more this ratio tends towards 3000 kg CO_2e per token (activity of maximum CO_2 emission for X-Large token, as presented in Table 2), the more efficient the variable considered is, in terms of reduction intensity.

4. Results

From November 6th 2020 to June 18th 2021, 85 workshop sessions brought together more than 600 participants (mostly academic professionals) from nine countries and more than 50 cities.

a. Alternative categorization

Fig 3 summarizes the categorization of alternatives in the form of a histogram, showing the frequency of each category in the proposed alternatives, and a pie chart for the relative contributions of lexical items to a given category.

In total, 407 different alternatives were expressed; some of them being considered by many participants, so that the total individual number of actions (move of tokens) performed to

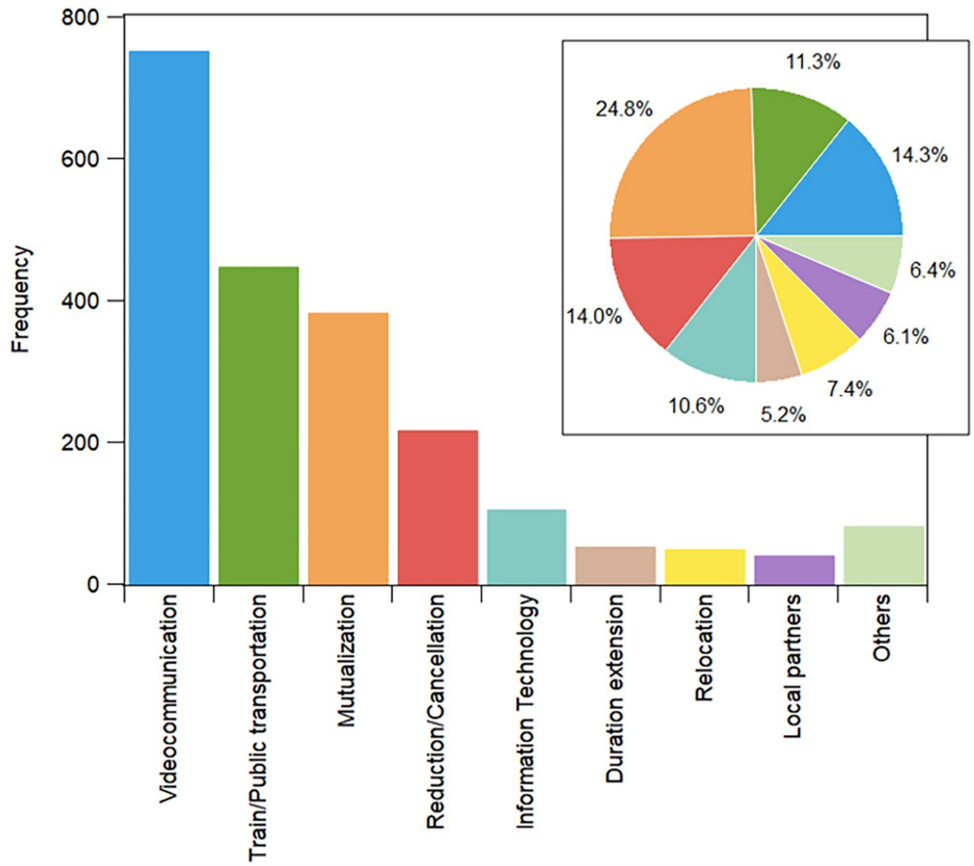

Fig 3. Classified alternatives by categories, and pie chart of the relative contributions of lexical items to each category. All lexical items are reported in the appendix.

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reduce carbon footprint was 2241. Videocommunication receives wide approval (35%) by most participants. This alternative is seen as an easy way to continue to engage in meetings, conferences and even PhD defense committees, or even replace in person training by remote or virtual sessions, while reducing their carbon footprint. It is worth noting that this alternative can also offer additional benefits such as reduced costs and personal life constraints while improving diversity, equity and inclusion (Skiles et al., 2022[40]). Replacing air flights by other public transportation options is the second most frequent suggestion (21%), although this option appeared sometimes limited for activities requiring the transport of instruments for instance. The third alternative–Mutualization (18%)–also presents the largest lexical field (~25% of the lexical items) since it requires a degree of interaction between two, or more, characters, and thus covers a great lexicological plurality. More than one hundred (101) different wordings of this alternative were voiced by participants. It gathers a variety of options such as combined trips for project meetings and/or conferences and/or field campaigns for a single individual, selecting one representative to attend a conference for a research group, training one person on many instruments for a field campaign or choosing similar mission fields. Reduction/cancellation (10%) has been chosen mostly for conference attendance (once every two years; limitation of either the number of people attending from the same research group or the number of international conferences per individual for instance), and voluntary decrease of research activities (waiving field trips, numerical computations, grant applications). Overall, these four categories account for more than 84% of all the alternatives proposed.

b. Trajectories of the different game tables

The GHG emissions trajectories are first presented through the absolute reduction of GHG of each game table (Fig 4A, *CF*); then, the relative reduction is shown (Fig 4B, *R*) to facilitate intercomparison given that not all the game tables/teams start with the same initial emission level (Table 1).

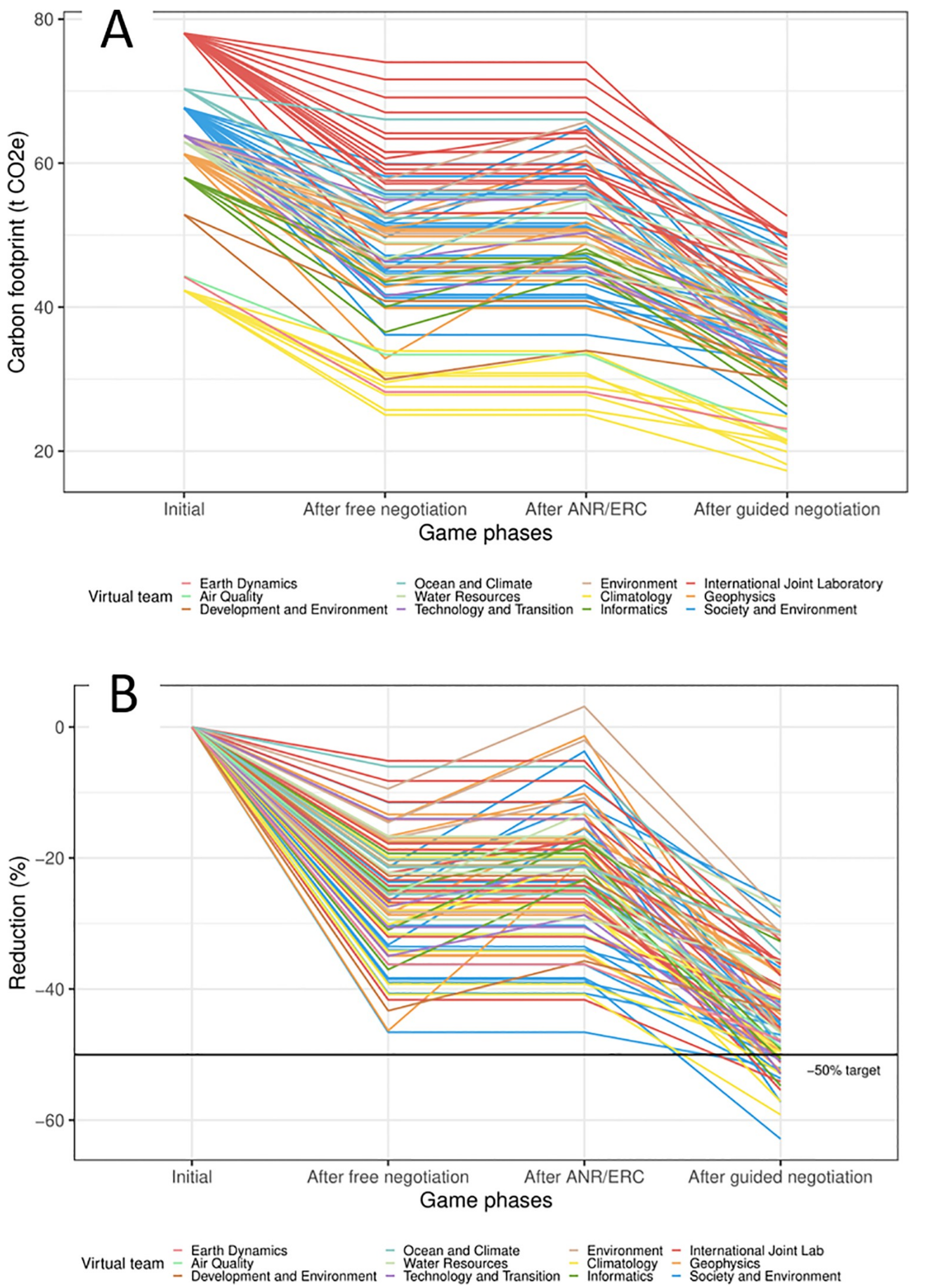

Fig 4. Virtual GHG footprint trajectories. (a) Absolute and (b) relative GHG trajectories for 85 game tables coloured by virtual teams. The horizontal solid black line represents the 50% reduction goal.

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The x-axis reports the four successive sub-phases of the role-playing game, as previously detailed in section 3b, phase 3, namely the initial footprint of the different virtual teams, the GHG footprint decrease after the free negotiation phase, French and European project grants, and the final reduction after the guided negotiation phase. Beyond the general decreasing trajectory of all broken lines observed in Fig 4A and 4B, we can emphasise a strong variety of initial budget (ranging from 42 tCO_2e to 78 tCO_2e per virtual teams), and of games trajectories.

Overall, in all workshop sessions, all virtual research groups managed to reduce their carbon footprint after the free negotiation phase. The variability of the final emissions at the end of the games overpasses the variability of initial GHG footprint, which clearly highlights the importance of the interactions between players during the game.

To compare the trajectories of the different tables, we displayed the relative reduction in GHG footprint (Fig 4B). Here, all tables start from 0% and reach between 5% and 45% reduction at the end of the free negotiation phase. As previously pointed out in Fig 4A, the successful application to French or European funding programs increases some of the footprints, sometimes wiping out the efforts that have been made during the free negotiation (e.g. one game of the Environment virtual team in brown). Finally, the range of reduction after guided negotiation is narrowed down to a final average reduction of 44% and a median of 46%.

The variability between games is high, the less efficient groups of participants reducing by 25–30% their emissions, while the most efficient ones reach reductions close to 60%. Despite the variety of situations, the virtual reductions obtained during all games are promising and show that substantial opportunities for GHG emissions reduction exist within the academic world. The high variability between games suggests that the reduction does not depend on the intrinsic characteristics of the twelve virtual teams (initial carbon footprint, distribution of motives, psychological profiles, etc.), but rather on the way participants of a game interplay through the ten characters they embody. To go further in the analysis, it is interesting to show the density distribution of the final relative GHG reductions, which is represented in Fig 5.

On this figure, no colour clusters are observable, suggesting that the final GHG footprint of virtual teams are approximately evenly distributed. For example, among the twenty games of the "Society and Environment" virtual team (blue squares), there is one at each extreme (-27.5% and -62.5%): the final result therefore depends more on social interactions that have been created during the game between participants, than on the characteristics of virtual teams played. However, in addition to this observation, there is a threshold effect related to the target of -50% proposed to win the game: before this target, the distribution increases gently and gradually, whereas after -50%, it suddenly drops. The target seems to affect the result obtained so that, as long as the target is not reached, the participants imagine solutions to reduce by 50% their emissions, but as soon as the target is reached, there is no reason to do more than necessary. The distribution peak, observed for a value of 50%, seems to indicate that the motivation of the participants is highly driven by the objective to be reached.

Another interesting aspect concerns the impact of additional fundings on the final GHG footprint. In Fig 5, games that did not receive additional fundings (i.e. additional GHG emissions) have an average reduction of -46.5%, logically beyond the ones that were overloaded by additional emissions. For games receiving additional fundings, the corresponding additional GHG emission averaged 12.8%. If participants were not influenced by these "penalties" the reduction of GHG emission should be around -33.9%, which is actually not the case. After the guided negotiation phase, the average GHG emission reduction was established at -42.8%. It means that corresponding participants made a substantial effort (+8.9%) to reduce their footprint and tentatively reach the targeted -50% of reduction. It is worth noting that none of the games with additional funding overpasses the target, while 14 of the 64 games without additional fundings overpass the target.

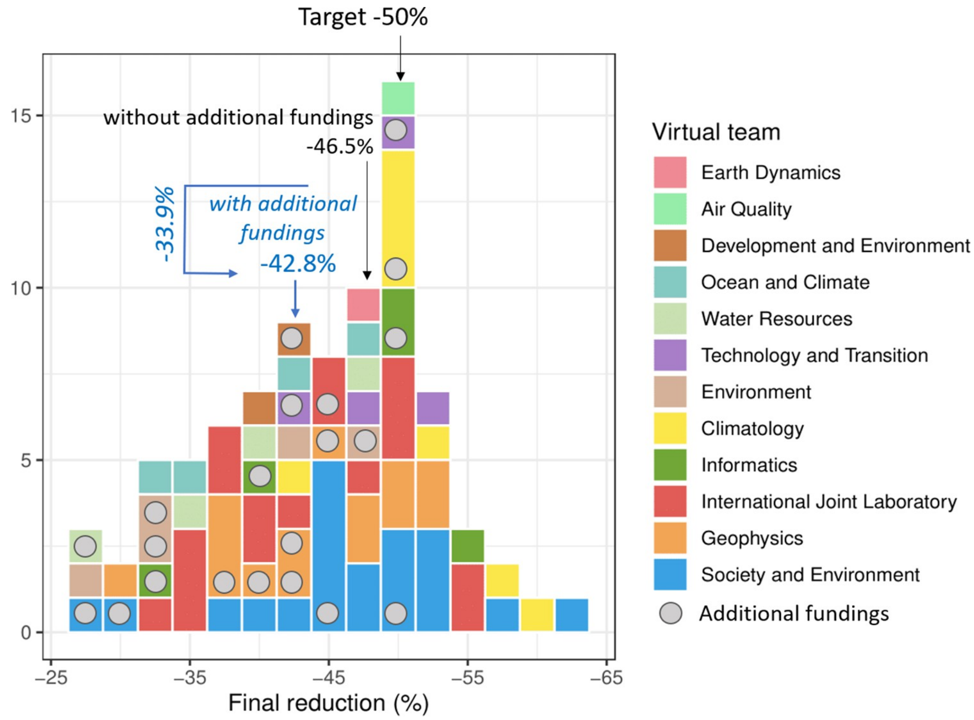

Fig 5. Density distribution of the final GHG reduction. It synthesised data presented in Fig 4B, for the 85 game tables colored by virtual teams. Black arrows indicates the -50% target and the mean reduction of games that did not obtained projects fundings (46.5%), The blue arrows indicate the mean reduction of games with funding (adding ~12.8% to the initial emissions) which could have been expected to achieve 33.9% but actually reached 42.8% reduction.

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c. Alternatives chosen and motives

The previous section indicates that the interaction between the participants and the resulting synergies predominate in the achievement of the reduction objective. However, are the alternatives chosen by the participants of the different games the same or, on the contrary, are they very diverse and dependent on the synergies specific to each game table?

To answer the question, the games were also analysed and compiled to emphasise the alternatives selected by participants, in the nine categories detailed previously (Table 3) and categorised in Fig 3. Results are reported in Fig 6.

The predominant alternative (36.1%) is the use of video communication tools. It is followed by the mutualization of some professional activities (22.3%) and by voluntary cancellation or reduction of research activities (14.4%). Train (6.9%), relocation (4.9%) and duration extension of journeys (4.7%) contribute a smaller part to the total virtual reduction. Finally, local partners (3.0%), IT optimization of numerical calculations (2.0%) and others (2.2%) account for a small share of the virtual emission reduction. Overall, almost 80% of the reduction is achieved through four categories of alternatives. Reduction of the GHG footprint through the implication of "local partners" category is believed to be underestimated, probably as a result of mixing with the mutualization category. The relatively low effect of IT optimization is attributed to the small fraction of emissions from computer simulations present in the 12 virtual teams considered. At a global scale, IT optimization is probably much more important.

Fig 7 shows which alternatives were chosen for each of major research activities, their corresponding alternative proportion, and how much GHG emissions were reduced.

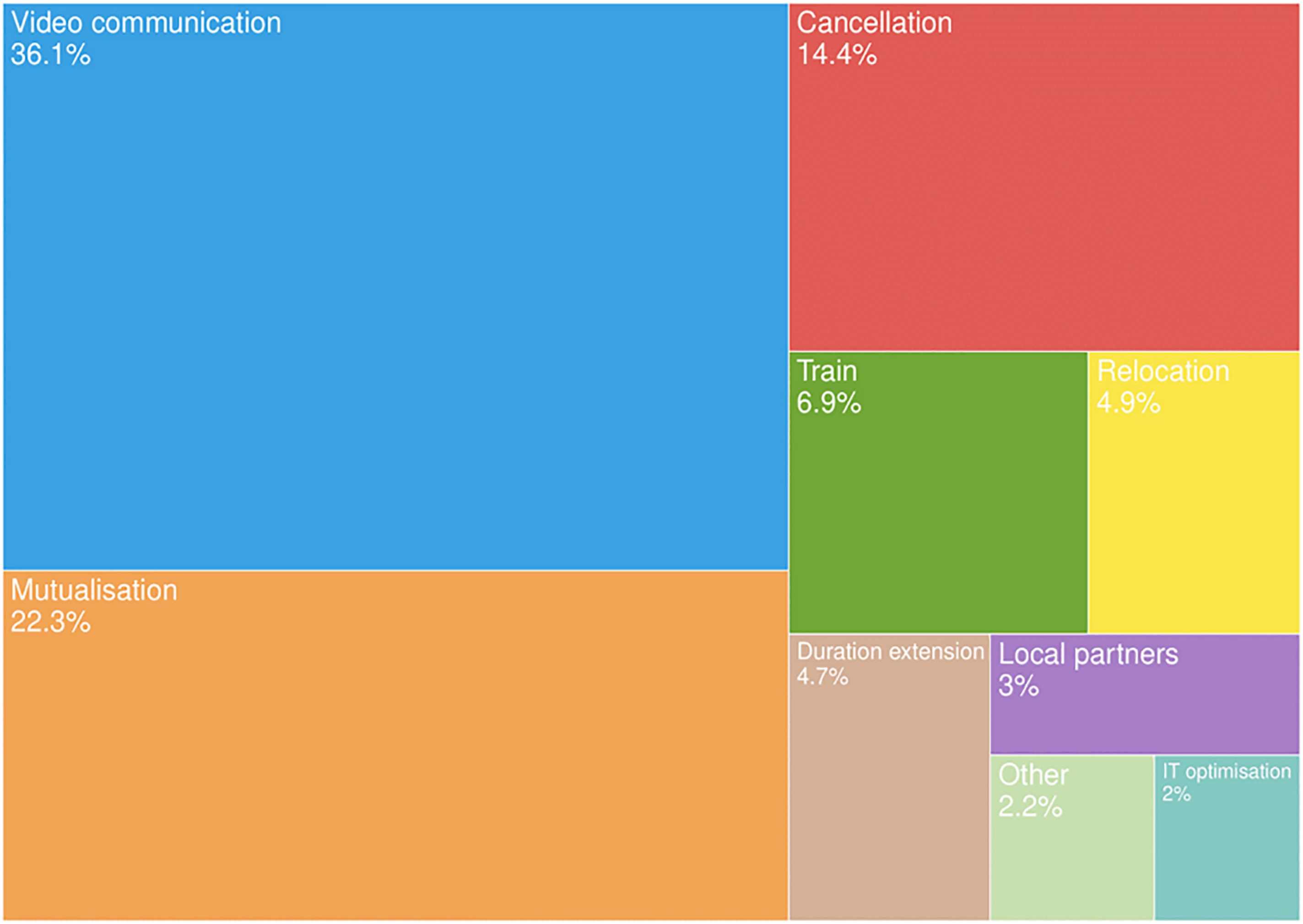

Fig 6. Repartition of the total GHG reduction by categories. The GHG reduction is, by average, 44% of the GHG initial footprint. The alternative categories are the ones expressed by participants and synthesised in Fig 3.

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Video communication (blue bars) is an efficient factor to reduce GHG footprint for six emission motives, by replacing physical meetings for conferences, projects, juries (PhD, staff recruitment, etc.) as well as training, institutional and expertise meetings by some distant video interactions. Field trips (on the continent or at sea), which are highly contributing to GHG footprint, are most often mutualized.

In general, the alternatives are dependent on the motives. A diversity of alternatives is required to maximize the reduction, which emphasizes the complexity and richness of interaction between participants.

Fig 8 shows in more detail the distribution of GHG emissions and pathways for reductions. The grey vertical bars and colored bands are proportional to the global GHG emissions for the 85 games considered. This Sankey diagram complements the information given in Fig 7. It becomes clearer why the total emissions from conferences are predominant: it is also the largest share of the initial distribution. Some motives appear to be difficult to substitute, for instance intensive computing and sea cruises, while others seem easier to reduce, juries in particular.

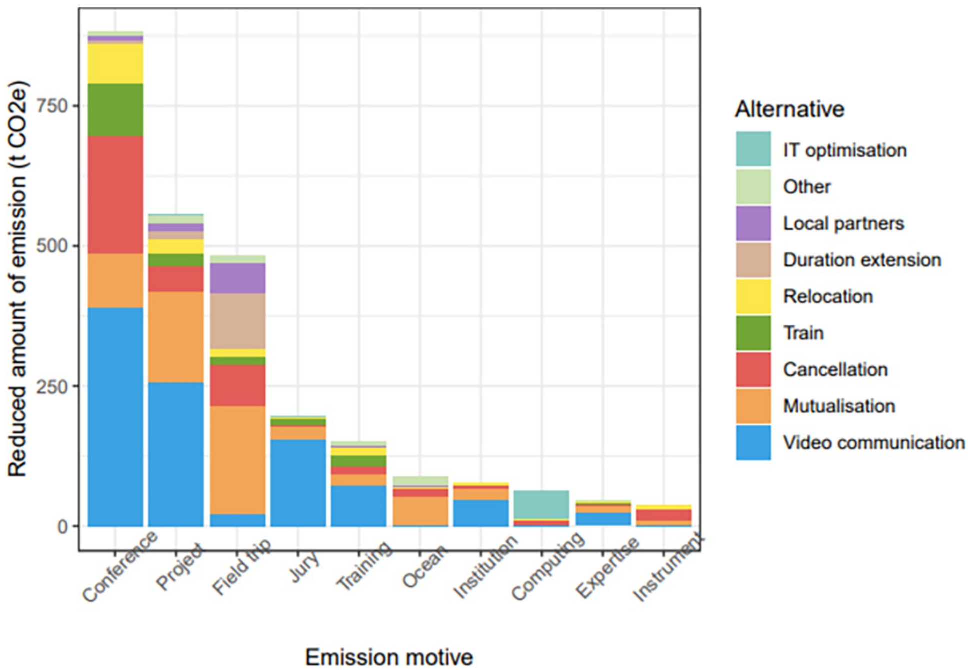

Fig 7. Absolute GHG reduction distribution. The reduction is subdivided by alternative categories depending on the emission motives: air travel to reach a conference, to meet for a project, for field trip, jury, for training, oceanographic campaigns, air travel for institutional meeting, cost of numerical computing, air travel to make an expertise, to access to a large unique instrument.

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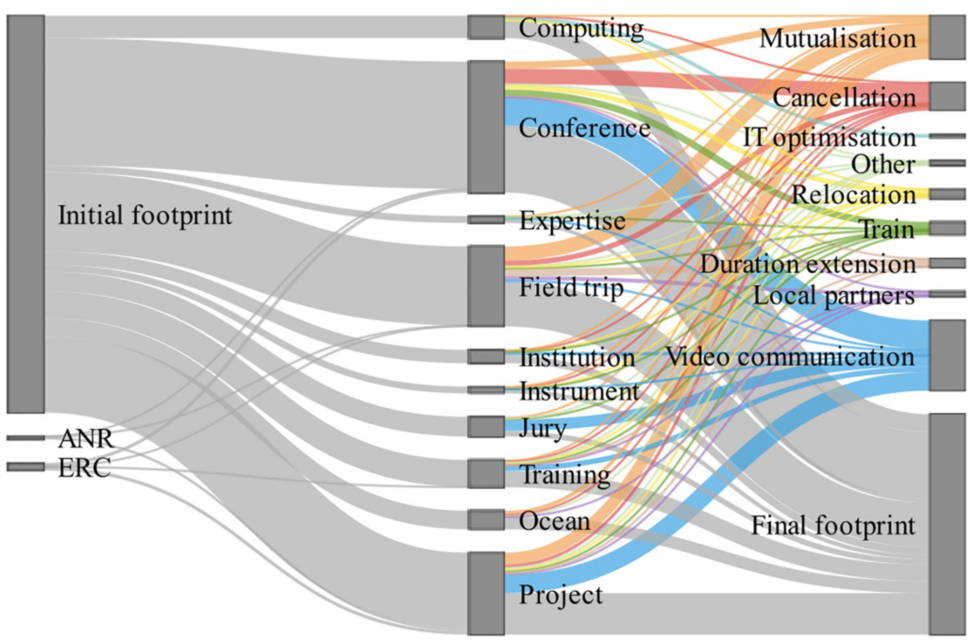

Fig 8. Distribution of the GHG emissions from the role-play initial balance to the selected alternatives and the final balance. On this Sankey diagram, the initial distribution of emissions can be seen, to which the emissions generated by the funded French and European projects (resp. ANR or ERC) during the game can be added. The initial distribution according to the motives can be seen in the centre of the diagram. On the right-hand side are the selected alternatives and the remaining emissions. The flow bands indicate the distribution between motives and selected alternatives.

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d. Frequency, spontaneity and emission intensity

As the role-playing phase takes place in two sub-phases of 20 and 25 minutes each, it is interesting to look at the influence of the time when the tokens are replaced for a given alternative. Three characteristics are particularly meaningful: first, the spontaneity of an action, i.e. the minimum time of appearance of the variable (motive or alternative); secondly, its frequency of appearance on all the games and finally its reduction intensity in kg CO_2e per token.

Fig 9 depicts the frequency of appearance of each alternative as a function of its spontaneity. The size of the bubbles is proportional to the reduction effectiveness of the alternative in kgCO_2e per token. Overall, four clusters of bubbles can be observed. First is the "video communication" alternative, which is very spontaneous (less than 10 minutes for its first appearance), very frequent (proposed by 95% of games) and rather effective. Cluster two includes three alternatives, namely "mutualization", "cancellation" and "train", which also come fairly early during games and remain fairly frequent but are unequally effective in reducing GHG emission, especially "train" which is rather low as it cannot substitute long-distance air travels. The following cluster is composed of the "duration extension" and "local partners" alternatives, which are proposed later and are less popular (around 25% of occurrence) but rather effective in terms of intensity of reduction. The last cluster includes "relocation", "IT optimisation" and "others". It arrives very late in the games, on average during the guided negotiation phase (after 30 minutes on average), is infrequent and unequally effective: "relocation" is the most effective alternative, while "IT optimisation" appears to be poorly effective.

Fig 10 represents the frequency of each motive removal as a function of its spontaneity. The participation in international conferences is globally the only motive to be withdrawn frequently (more than 95% of games played) and getting a high spontaneity (<10min). In contrast and logically, flight to access to "unique instruments" are the least frequently removed (just over 50% of game tables initially having them), which is understandable as it is the core of

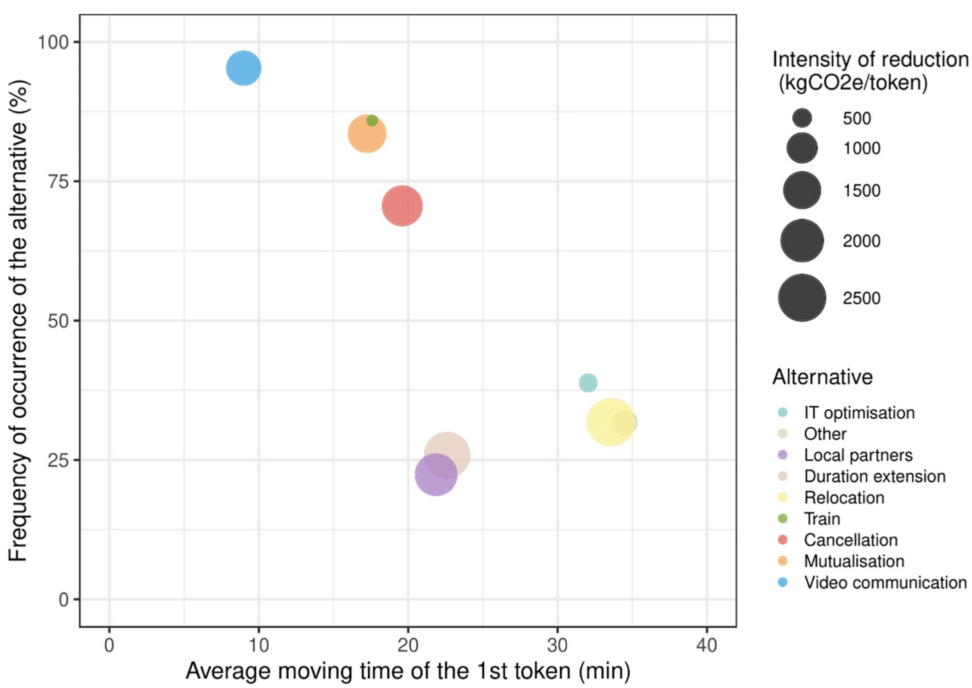

Fig 9. Spontaneity of the different alternatives sized by reduction intensity.

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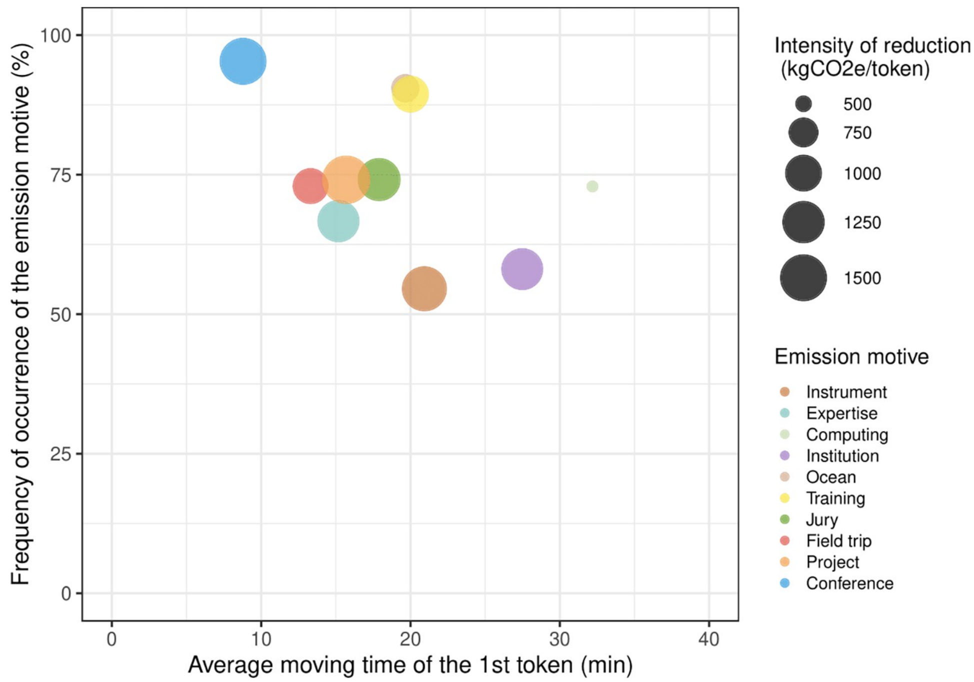

Fig 10. Spontaneity of the different emission motives removal. It is sized by reduction intensity. The size of the bubbles is proportional to the reduction effectiveness of the motive removal in kg CO_2 equivalent per token.

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some research activities and cannot be substituted. Finally, IT optimization is less spontaneously mentioned (beyond 30 minutes of play).

The effectiveness of reduction, represented by the size of circles, is also rather variable, ranging from more than 1500 kg CO_2e per token for projects and conferences meetings, to less than 500 kg CO_2e equivalent per token for computing.

5. Discussion

a. Synergy during the role-play sessions and influence of the target

According to Pohlmann et al. (2021)[41], the normalisation of climate-friendly behaviours in a given social group will not occur through the sum of individuals. Gamification thus often provides interactive spaces where reality can be experienced and transformed, which is a rich basis for knowledge creation (Kolb, 2014[42]).

Our study shows that most of the variability of the results can broadly be explained by two independent factors: the synergy that was created between the participants during each game and the target that is given to win the game (in our case -50% of GHG footprint). As far as synergy between participants is concerned, an in-depth anthropological and sociological work would be needed to assess the brakes and leverages to GHG footprint reduction (Whitmarsh et al., 2020[20]). An in-depth analysis of this hypothesis in this study goes beyond our scope but is a key perspective for further analysis of the data collected during the games.

Focusing on a more quantitative analysis, some interesting elements can be deduced from final GHG footprints (Fig 5). In this figure, the density distribution shows an asymmetry, which corresponds to a threshold effect: below 50% of reduction, the game tables are distributed rather gradually, but once the objective is reached, the density distribution suddenly drops. Thus, as long as the objective is not reached, the participants make all the efforts they can and as soon as the objective is reached, the participants stop making efforts. The question then arises whether setting a target of 75% would also result in this threshold effect with an average reduction slightly below the target. We may hypothesise that a reduction of 50% finally remains acceptable and reachable, but a target at 75% would probably discourage participants and require more profound and systemic changes of the academic sector practices. It is worth noting that the median of final reduction was about 45% which is believed to be a positive signal for reaching significant reduction of GHG emission in real life.

b. Frequency, spontaneity and effectiveness of alternatives

Here, our interest was to identify how to articulate the emission motives and the alternatives, as expressed in Fig 8, in order to build realistic scenarios for reducing the carbon footprint of the academic world. Virtual teams in *MaTerre180'* are as much realistic as possible to prevent too wide a gap between the game and the real world. Besides, once awareness is raised in the first phase, some individual choices can be made—when possible—without the approval of the employer or much impact on one's career (such as meal choices, mode of commuting to work), yet have some benefits on the academic footprint in real life although they are not explored in the game itself. In order to analyse the reduction choices made by the participants, it was decided to focus the study's attention on specific characteristics. To do this, it is important to understand which emission motives are favoured for reduction and towards which alternatives by looking at the frequency, spontaneity, effectiveness and efficiency of these choices (Figs 9 and 10). However, passing from the virtual space of a role-playing game to the real world of research, may introduce unexpected difficulties due to the current functioning of research, which promotes individual performance and competition (van Dalen, 2021[43]) instead of building bridges toward global sustainability (Irwin et al., 2018[44]).

Our results showed that 80% of the GHG reduction was possible thanks to four alternatives, namely video communication, mutualization of means or activities, cancellation of activities and lower carbon emission transportation (train). The use of video communication is the most spontaneous and frequent proposal, which enables the greatest reduction (16.2%), because it can be adapted to a large number of activities, with the notable exception of field/sea campaigns. The spontaneity and efficiency for video communication have probably been propelled by the COVID-19 pandemic crisis that has recently imposed such means of communication due to lockdowns and remote working (Nguyen et al. 2020[45]). Video communication practice had however already been raised within the scientific community as an alternative to conferences (Jordan and Palmer, 2020[46]). Nevertheless, the advantages and disadvantages of virtual conferences are debated. Another suggested option is to attend conferences in person, but to be more selective (see below, cancellation). The second option is the mutualization of activities or means, which also leads to a strong overall reduction of GHG footprint (10.0%) by combining several field trips of different purposes or by delegating specific tasks to limit the number of participants during field/sea campaigns. Yet, experts of oceanographic campaigns consider that a reliable mutualization of onboard activities is an uneasy task. In real life, one can anticipate non-negligible organisational obstacles and an expected resistance of researchers and their stakeholders (community, hierarchy, partners) for such suggestions. While grouping several activities on a personal basis is not excessively complex, mutualization between colleagues requires a high degree of communication, preparation and trust. At present, mutualization is not sufficiently recognized by academic institutions to become popular, in view of the time required and the risks involved for careers, in case of failure of uneasily rescheduled campaigns. According to Shove and Walker (2014[47]), individual actions are embedded in institutional, social and infrastructural frameworks, which ensure that climatedamaging behaviours remain the norm. The academics need to be proactive to shift these norms through more mutualized and frugal research. The third alternative concerns cancellation or rationalisation of research activities. It is by nature very simple to be done technically, but seems to be over-represented in our results. The main limitation is the psychological acceptance by participants, in link with social habits and pressures (Gifford, 2011[48]). The lack of institutional recognition of the efforts made and risk-taking by researchers in the case of a cancellation or drastic reduction of field/oceanographic surveys seems also to be a limitation. It is the same in the case of limitation to in-person meeting participation. As long as a carbon quota or any other indicator, based on the sustainability of activities, is not put in place by academic institutions, reducing one's activity brings at best a saving of time and an improved work-life balance, at worst, a devaluation of research performance and researcher's recognition. An in-depth analysis of costs and benefits for the society should be considered. The fourth alternative is train travel, which is often mentioned in the literature as a solution for decarbonizing research. However, train travel quickly reaches its limits in the sense that it is neither easily accepted to take the train if several train changes are required or heavy/cumbersome equipment needs to be transported. Trains cannot substitute long-distance air travel. For most regional activities however, train is even very efficient (Ciers, et al., 2019[49]). The train must thus be promoted both as an efficient practice on a regional scale, and as a marker of change in our practices.

The remaining 20% of the reduction is made up of solutions that occurred less frequently and were less spontaneous, but which can compensate for the limitations of the first four. Relocation, coupled with the use of trains, is thus very efficient as it directly addresses long-distance air travel, particularly for conferences. The extension of the mission duration is similarly very interesting but is proposed more specifically for field trips or sea cruises which allow for more expatriation. Local partners and expatriation are specific to some research groups and topics. Reducing the corresponding GHG footprint will require first to understand people's beliefs, values and norms, second to engage in-depth discussions between all actors and policy makers to break psychological and other limits (Gifford, 2011[48]).

Regarding the emission motives, they are globally withdrawn from the playmat in proportion to their initial distribution within the eighty-five tables. Conferences are naturally removed the fastest and most often, but this should not overshadow the other motives for the teams' emissions, as is often the case in scientific works that consider conferences for the most part. However, this raises the question of the acceptability of replacing a conference with a videoconference or cancelling it, and the valuation of conferences in the research indicators. There are also many motives that can be played on. For example, thesis juries are especially reduced, as they can essentially be carried out by videocommunication, with an associated gain in personal life quality. Conversely, certain motives are under-represented, like oceanographic surveys, intensive computing or travel for the use of unique instruments, as they are specific to the activity of the research labs and so more difficult to reduce, which may explain the lower spontaneity and frequency for the latter two.

c. Steps and timetable for achieving the -50% target by 2030

The key point now is to consider how to transform the virtual pathways of GHG, expressed during the role play phase, into real measures. In the virtual format, participants detach themselves from their emotions but have the difficult task of projecting themselves into the skin of a fictional character. Some participants may find it difficult to make this change of posture and to become imbued with the personal motivations, posture and convictions of the embodied characters. The difficulty is even greater when each participant plays two characters, and when these characters' behaviour and profile are different from their own (for instance when a PhD student must play a senior researcher). The complexity therefore lies in knowing to what extent the proposals emanating from fictional discussions can be directly transposed into the everyday life of an actor in the academic world. Nevertheless, no justification could discredit an alternative a priori. It is still necessary to encourage their implementation in order to judge their acceptance in the framework of a functional research group. Two main directions for their implementation can be distinguished:

First, promoting and recognizing the efforts made by individuals to reduce one's GHG footprint would be a preliminary step. One point that came up several times in the discussions during the debriefing phases was the importance of indicators of academic performance. Indeed, the current indicators encourage productivity and do not take into account the social and ecological impact of research and education activities, in particular in terms of GHG footprint. It seems inappropriate to keep the same evaluation criteria for academia in the context of the socio-ecological transition. We know that conferences play a major role in the dissemination of work and the construction of a professional network. They are more important for young researchers compared to senior ones who have already obtained permanent positions and built up their network. Nevertheless, it is the latter who travel the most to participate in international conferences (Wynes, 2019[25]). The evolution of indicators and evaluation criteria therefore appears to be a relevant option for taking better account of criteria compatible with global limits.

The second option is for the functional teams to take control of the results. The digital interface used during the role-playing phase of *MaTerre180'* constitutes a powerful tool for developing new techniques of communication and negotiation between peers. We can imagine that some research groups could take advantage of this transition support system to experiment with various strategies of research projects and define the ones that best balance benefits for society and sustainable GHG footprint.

In their exhaustive review, Flood et al. (2018[50]) reported various climate related games or role playing focusing on water management, long term farming or risk disasters; but none of them was dedicated to the academic world and its non-negligible GHG footprint. Knowing the peculiar role of scientists in society, we may hope that the use of a tool such as *MaTerre180'* could accelerate a shift in the scientific community and provide a persuasive argument for a broader shift in other sectors.

Transition support system could certainly facilitate the transition, but this will depend on our capacity to follow at least two recommendations (Galeote et al., 2021[27]): first, it is important to promote interventions in emerging and developing countries and to extend the target to young students and more social, political, and economic actors. Secondly, gamification and transition support system techniques should be massive and lead to large data series in order to get statistically robust and unbiased scenarios of reduction. Some collaboration with research institutions with a broad national and international presence, could favorably help for reaching these recommendations.

d. Limits and ongoing improvements of *MaTerre180'*

Several limits of the current set up of the workshop are already identified and will lead to future, improved versions of the workshop. First, the rationale of the workshop was designed before the COVID crisis which has imposed most researchers to drastically reduce their travels. However, it is clear that the possibilities and incentives for long distance travel for various reasons (jury, conferences, fieldwork) are currently resuming, and therefore the need for research communities to reflect on how to perform sustainable research is very timely.

Additionally, the COVID crisis has made concrete many of the alternatives discussed during the role-played negotiations (e.g., relocation, online meetings, etc.), which could facilitate discussions and implementations of these options in both virtual and actual research units.

Second, the workshops were devised based on CO_2e budgets which considered air travel as the dominant source of emission. However, recent GHG budgets from research institutions emphasised that together with air-travel, research-driven purchases are often a dominant source of emissions (Martin et al., 2022 [51]). They are currently being included in the initial CO_2e budget and will require different alternatives than the ones envisioned for air travel reduction. Obviously, the complex and international activities of research institutions mean some substantial part of their CO_2 budget may still not be captured by the game (e.g., large infrastructures and satellites, Knödleser et al., 2022 [52]). Nevertheless, the goal of the game is to accelerate the emergence and implementation of alternatives allowing to decarbonize research activities, even if all sources and alternatives are not adequately quantified and decarbonisation itself cannot be the only measure of sustainability. The game can be currently played for research activities located in France (where electricity is mostly decarbonized), since the emission factors associated with activities depend also on the energy mix of each country.

Last, a limit of the game may be its tendency to underestimate resistance to alternative ways of performing research. Indeed, the proportion of researchers with low environmental commitments may be larger than in virtual teams, and actual research unit heads may not always be very pro-active in negotiating overall reduction of CO_2e emissions, as it is assumed in the second phase of the role-play game. Varying the proportion of virtual characters resisting changes and analysing separately games outcome as a function of the personality of the virtual team leaders may be a way forward to assess this potential bias.

6. Conclusion

The authors of this study are convinced that the state of scientific knowledge on the current and coming social and ecological crises, caused or enhanced by global warming, is not enough to bring about a systemic and rapid change that is commensurate with the issues at stake (Hulme, 2020[22]). In this context, the academic world is not an exception and must act and embody changes (Attari et al., 2016[18]; Whitmarsh et al., 2020[20]). Mathematically-based methods, such as simply assessing the GHG balance of research activities (e.g. Mariette et al., 2022[21]), are essential but lack the ability to engage deeply all those involved in academic research, from the management to the technical staff, from PhD students to senior researchers. For that purpose, a game-based transition support system, MaTerre180' (https://materre.osug.fr/), was created to build scenarios of GHG emission reductions in the academic community. MaTerre 180' reproduces–even at a small scale–a laboratory group where people perform various duties, are at all levels of their career and can pursue different professional objectives, not necessarily compatible with a path for emission reduction. This tool has been deployed during the year 2021 with around 600 participants. The analysis of all the games played is encouraging and expresses clear pathways for reductions: given a target of 50% reduction, the range of GHG reduction at the end of the game-played phase is between 25 to 60% with a median reduction of 46%, independently of the virtual research team played. Although the game is time-limited, its potential to recreate similar group dynamics as in real life interactions was appreciated by the participants. This result highlights that, virtually, the objective of 50% of GHG emission reduction in 2030 is reachable for the academic world.

More in-depth analyses were conducted to understand the dynamics of reduction, the remaining obstacles to endorse a reduction strategy, and to spark all ideas about possible alternatives. The alternatives allowing the greatest reduction are the video communication tools

(35%), followed by the mutualization of the professional activities and the voluntary cancellation or reduction that represents 22 and 14% of reduction, respectively. The remaining 28% of reduction is composed by the use of trains as a transport alternative, the relocation of professional activities, the duration extension of some missions, the optimization of the information technology and other marginal ideas. Our results also confirm the necessity of alternatives adapted to specific research activities: the most effective tool to reduce the GHG emissions from conferences, projects and juries is, as expected, the video communication tool whereas mutualization and duration extension are the most important alternatives for field trips. The initial footprint of the research activities explains the dominance of some activities to the total emission that remains even after the game phase (like conferences). It also shows the small part of cancellation in the GHG emission reduction from the different categories, except for conferences, and thus shows the relatively easy way for academics to reduce their emissions without tremendously affecting their research activities. Finally, the analyses of all the game dynamics, i.e. when, which and how often the alternatives are proposed, show some obstacles to use some types of alternatives and the necessity to have a person that guides the discussion (second part of the game phase): relocation, local partners and computing optimization need more guided discussions than individual choices of video communication, and free discussion for mutualization. Overall, most solutions proposed by the participants are known or have already been experienced by them, but calculating in real time the potential of each of them to reduce effectively the GHG emissions of the team makes them more palatable.

Following the informative documents provided ahead of the game phase, the authors expect the game to trigger some behavioral changes at the individual (personal) level (such as the use of decarbonized transportation outside of commuting/business trips, or the decrease in meat consumption). Moreover, the game can contribute to professional structural changes by raising a collective momentum on this issue that warrants collective endeavors on the part of the academic community.

Diverse game reviews from the last decade show that the tendency of gamification has only grown in recent decades (Reckien and Eisenack, 2013[53]; Flood et al., 2018[49]; Galeote, 2021 [27]). However, to the best of our knowledge, this is the first time that such a role-playing game is deployed and used to determine the possible scenarios to reduce GHG emissions in the academic world. Gamification is relevant because it allows participants to fail with low consequence (Plass et al., 2015[54]). Some further sessions of *MaTerre180'* need to be performed in order to consolidate the results and explore the participants sociological synergies during the workshops: changing the 50% target of GHG emission reduction, using virtual teams exploring other field of research, adding other kinds of virtual characters, incorporating the purchases (services, consumables, materials and equipments) into the initial carbon budget, etc.. Additionally, deploying *MaTerre180'* at different scales and within varied academic contexts (universities vs. national research institutes, students vs. university staff) will help to tackle possible biases. Last but not least remains the transition between virtual and real world, i.e. to find the method to adapt the scenarios imagined with the virtual game-based tool into the real world of academic research. This necessarily requires the participation and involvement of the institutional governance of research organisations.

Supporting information

S1 File. Details on tokens and characters of the "geophysics" research team.
(DOCX)

S2 File. Details on the 2241 expressed alternatives.
(DOCX)

S3 File. Gender distribution by sessions: female and male for both facilitators and participants are reported in orange and green horizontal bars, respectively.
(DOCX)

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Author Contributions

Conceptualization: Nicolas Gratiot, Géraldine Sarret, Géremy Panthou, Benoît Hingray, Nicolas Champollion, Olivier Aumont, Florence Michau, Cathy Grevesse.

Data curation: Nicolas Gratiot, Olivier Dangles, Serge Janicot, Miriam Candelas, Géraldine Sarret, Géremy Panthou, Benoît Hingray, Nicolas Champollion, Julien Montillaud, Pascal Bellemain, Odin Marc, Cédric-Stéphane Bationo, Loïs Monnier, Laure Laffont, Marie-Alice Foujols, Véronique Riffault, Liselotte Tinel, Emmanuel Mignot, Nathalie Philippon, Alain Dezetter, Alexandre Caron, Guillaume Piton, Aurélie Verney-Carron, Nelly Bardet, Florence Nozay-Maurice, Anne-Sophie Loison, Franck Delbart, Sandrine Anquetin, Françoise Immel, Christophe Baehr, Fabien Malbet, Céline Berni, Laurence Delattre, Vincent Echevin, Elodie Petitdidier, Olivier Aumont, Florence Michau, Nicolas Bijon, Jean-Philippe Vidal, Sébastien Pinel, Océane Biabiany, Cathy Grevesse, Louise Mimeau, Anne Biarnès, Charlotte Récapet, Morgane Costes-Thiré, Mariline Poupaud, Maialen Barret, Marie Bonnin, Virginie Mournetas, Bernard Tourancheau, Bertrand Goldman, Marie Paule Bonnet, Isabelle Michaud Soret.

Formal analysis: Nicolas Gratiot, Jérémie Klein, Marceau Challet, Serge Janicot, Géremy Panthou, Benoît Hingray, Nicolas Champollion, Odin Marc, Marie-Alice Foujols, Florence Michau, Sébastien Pinel.

Funding acquisition: Nicolas Gratiot, Olivier Dangles, Julien Montillaud, Anne Delaballe.

Investigation: Nicolas Gratiot, Marceau Challet, Julien Montillaud.

Methodology: Nicolas Gratiot, Géraldine Sarret, Géremy Panthou, Benoît Hingray, Nicolas Champollion, Emmanuel Mignot, Nathalie Philippon, Guillaume Piton, Françoise Immel, Olivier Aumont, Florence Michau, Océane Biabiany, Cathy Grevesse.

Project administration: Nicolas Gratiot, Odin Marc, Nelly Bardet, Florence Michau, Jean-Philippe Vidal, Sébastien Pinel.

Resources: Nicolas Gratiot, Olivier Dangles, Miriam Candelas, Géraldine Sarret, Géremy Panthou, Benoît Hingray, Nicolas Champollion, Julien Montillaud, Odin Marc, Cédric-Stéphane Bationo, Loïs Monnier, Laure Laffont, Marie-Alice Foujols, Véronique Riffault, Liselotte Tinel, Alain Dezetter, Alexandre Caron, Guillaume Piton, Anne Delaballe, Florence Nozay-Maurice, Sandrine Anquetin, Françoise Immel, Fabien Malbet, Céline Berni, Nicolas Bijon, Jean-Philippe Vidal, Océane Biabiany, Cathy Grevesse, Louise Mimeau, Anne Biarnès, Charlotte Récapet, Morgane Costes-Thiré, Mariline Poupaud, Maialen Barret, Marie Bonnin, Virginie Mournetas, Bernard Tourancheau, Bertrand Goldman, Marie Paule Bonnet, Isabelle Michaud Soret.

Software: Pascal Bellemain.

Supervision: Nicolas Gratiot, Anne Delaballe.

Validation: Nicolas Gratiot, Serge Janicot, Miriam Candelas, Géraldine Sarret, Géremy Panthou, Benoît Hingray, Julien Montillaud, Florence Michau, Jean-Philippe Vidal, Sébastien Pinel.

Visualization: Jérémie Klein, Marceau Challet, Pascal Bellemain.

Writing – original draft: Nicolas Gratiot, Jérémie Klein, Marceau Challet.

Writing – review & editing: Nicolas Gratiot, Olivier Dangles, Serge Janicot, Miriam Candelas, Géraldine Sarret, Géremy Panthou, Benoît Hingray, Nicolas Champollion, Julien Montillaud, Pascal Bellemain, Odin Marc, Cédric-Stéphane Bationo, Loïs Monnier, Laure Laffont, Marie-Alice Foujols, Véronique Riffault, Liselotte Tinel, Emmanuel Mignot, Nathalie Philippon, Alain Dezetter, Alexandre Caron, Guillaume Piton, Aurélie Verney-Carron, Anne Delaballe, Nelly Bardet, Florence Nozay-Maurice, Anne-Sophie Loison, Franck Delbart, Sandrine Anquetin, Françoise Immel, Christophe Baehr, Fabien Malbet, Céline Berni, Laurence Delattre, Vincent Echevin, Elodie Petitdidier, Olivier Aumont, Nicolas Bijon, Jean-Philippe Vidal, Sébastien Pinel, Océane Biabiany, Cathy Grevesse, Louise Mimeau, Anne Biarnès, Charlotte Récapet, Morgane Costes-Thiré, Mariline Poupaud, Maialen Barret, Marie Bonnin, Virginie Mournetas, Bernard Tourancheau, Bertrand Goldman, Marie Paule Bonnet, Isabelle Michaud Soret.

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