

Does low-carbon transition encourage equity principles ?

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14 Abstract

15 This study investigates researchers' research practices using the *Ma Terre* (MTr)
16 serious game, in which participants adopt fictional, but realistic, characters representing
17 research team members. Across eighty five *Ma Terre* workshops gathering three hundred
18 academics issued from twelve research domains, teams negotiated measures to reduce
19 their carbon footprint by 50%, considering travel research activities. Initial and final
20 greenhouse gas emissions (GHG) and the heterogeneity of distribution within teams were
21 quantified using the Gini coefficient (G), to assess whether pathways for low-carbon
22 practices are accompanied with mechanisms of equity. Results show firstly that, within the
23 game, initial inequality does not limit research teams' capacity to reduce emissions: highly
24 unequal teams, characterised by G values higher than 0.5, achieved GHG emission
25 reductions comparable to more egalitarian teams. Secondly, teams starting with egalitarian
26 norms have widened the range of possible low-carbon trajectories, while high initial
27 inequalities have narrowed them. Thirdly, the occurrence of external and randomly
28 distributed events, such as substantial additional funding, increased participants' effort and
29 in most cases led to more collaborative behaviour that at the end reduced inequity. After
30 such events, a statistical correlation emerged between carbon reduction and decreases in
31 the final G coefficient. Two limits to the current study will be considered for further
32 perspectives : while the G coefficient effectively summarizes inequality, it does not capture
33 the nature of disparities or differences in individual effort, highlighting the need to
34 complement measures quantifying the level of equity with qualitative dimensions. In addition,
35 the gamified setting primarily reflects intentions and attitudes rather than actual behaviour,
36 influenced by engagement, social norms, and workshop context. To conclude, these findings
37 underscore the need for targeted strategies to promote both environmental sustainability and
38 social equity in university research, particularly by creating opportunities or momentum that
39 motivate to exert stronger effort.

40 Author Summary

41 Since the Meadows report in 1972, academic studies have continually refined our
 42 understanding of the biophysical limits of the Earth, and the need to thoroughly re-examine
 43 and re-define our interdependencies between humans and non-humans socio-ecosystems
 44 to ensure habitability. These knowledges are an essential prerequisite for individual and
 45 collective awareness, but it is not enough to prompt action. To facilitate creative processes
 46 and stimulate a desire for change, we developed a serious game called *Ma Terre en 180*
 47 *minutes* [Gratiot et al., 2023]. It enables academic staff to examine their professional
 48 practices and attitudes, and to collectively outline approaches compatible with the Paris
 49 Agreement, namely halving our “carbon” emissions. As inequalities continue to grow both
 50 within countries and between them, are the scientists at the forefront of knowledges able to
 51 identify low-carbon alternatives within their own professional fields that respect planetary
 52 boundaries and promote principles of equity ?

53 Whilst the goal of reducing the carbon footprint by 50% is a laudable intention, widely
 54 supported by scientists, the principle of a proportionate, equitably distributed effort does not
 55 seem to be a given, and is explore trough this study.

Introduction

Scientists' meetings and reports, notably the IPCC Special Report on Global Warming of 1.5 °C [Masson-Delmotte et al., 2018], have repeatedly emphasized the urgent need to drastically reduce greenhouse gas (GHG) emissions across all sectors to limit the magnitude of climate change and its impacts on humanity and on the biosphere. Scientists actually face a paradox: while calling for behavioural change, they often emit more than average [Poupaud et al., 2025]. To face the contradiction, the academic community has begun to critically examine its own practices to decrease the environmental footprint [Berné et al., 2022 ; Hardy et al., 2023 ; Marc et al., 2024] and propose alternatives, noticeably in high-emission academic disciplines, such as astrophysics [Gokus et al., 2024], neurosciences [Corneyllie et al., 2025] and polar research [Moraru et al., 2024] for instance. Nevertheless, such research activities, with the need for international cooperation, figure air travel as an important contributor to research-related emissions [Blanchard et al., 2022]. And paradoxically, climate researchers take more flight over years than other academics [IRD, 2024], which can weaken the credibility of scientific messages to society, and stimulate debates on fair emissions reduction within the academic world.

Beyond ecological concerns, sustainability transitions must actually integrate social justice, so that the effort to lower GHG emissions and mitigate human impacts on the Earth system contributes to reducing inequities. Conversely, global warming can exacerbate political and social dynamics that undermine environmental protection and inequality reduction, for instance through the rise of polarizing, petro-masculinity leaders [Daggett, 2018 ; Millward-Hopkins et al., 2022]. By eroding international cooperation and national cohesion, climate change could threaten the collective action needed to address it.

To fight again this paradox, urgent, positive scenarios are therefore required and Science should contribute to its emergence. Marked inequities persist within the academic system

itself, particularly in research involving the Global South [Fanchette et al., 2022]. Access to resources, funding, mobility, and digital tools is uneven both within laboratories and across international partners. Efforts to reduce the carbon footprint of laboratories, especially by limiting travel, may unintentionally deepen these disparities.

In this context, [Poupaud et al., 2025] examined how research can minimize its carbon footprint while accounting for scientific requirements and global disparities. It advanced three complementary approaches: quantitative assessment, qualitative analysis through semi-structured interviews, and participatory forum theatre, to rethink research practices in collaboration with the Global South. The implementation of such approaches depends on sustained institutional support and careful consideration of the working conditions and constraints experienced by research personnel [Poupaud et al., 2025]. At the same time, critiques of the accelerating pace of academia, increasing bureaucratisation, the race for publications, and mobility incentives tied to scientific and institutional recognition stress the structural obstacles that hinder the adoption of more sustainable practices [Baxerres et al., 2023 ; Ben-ari et al., 2023 ; Poupaud et al., 2025]. Together, these analyses call for a profound reconfiguration of research practices and for rethinking the production of knowledge. [Poupaud et al., 2025] study confirms that it is essential for institutions to support reflections and initiatives driven "from below", particularly at the level of research units, through participatory approaches [Baxerres et al., 2023 ; Ben-ari et al., 2023].

Building on this framework, this study assesses decarbonization scenarios in the academic community. Using the serious game *Ma Terre* [<https://materre.osug.fr/>], researchers simulate a team's meeting to explore intentions to change their practices to reduce emissions, linked with travel (including conferences, fieldwork, and institutional meetings), by 50 % in line with the Paris Agreement. The analysis considers both reductions in GHG emissions and the evolution of inequalities in carbon footprints, using the G coefficient [Lechthaler et al., 2025].

This study tends to address the following research question: to what extent can a serious game reinforce intentions to reduce GHG emissions associated with researchers' travel while reducing emissions inequities ? The objective is to examine whether participatory exercises can simultaneously promote a reduction in GHG emissions and a heightened awareness of social justice. It is hypothesized that serious game, collective targets and normative expectations will: increase motivation to decrease carbon footprint, regardless of the initial disparities (H1) ; influence the distribution of GHG emissions among individuals, presumably reducing inequality (H2) ; rise the difficulty of reducing the carbon footprint and associated inequities through the occurrence of an external event, such as new project funding - mainly because seniors are more likely to obtain such financing than juniors (H3).

The study presents the dataset and the analysing method, the results regarding the three hypotheses (H1 to H3) and finally discusses them together with showing the study limits and interaction with existing works. Using the serious game *MTr*, this study examines the collaborative capacity of a research team to design action plans aimed at transforming work practices in order to reduce their GHG emissions, while assessing changes in carbon-footprint inequalities.

Results

I Influence of gaming on reducing carbon footprint (H1)

1. Initial states

Table 1 presents the number of workshops conducted in each research-team category, along with their initial carbon footprint, at the beginning of workshops. The *MTr* digital interface allows participants to continuously and dynamically monitor the effects of their proposals on the GHG emissions and potential reductions.

Virtual research teams	Techno et transition	LMI	Environnement	Géophysique	Informatique	Climatologie
Workshop numbers (with extra funding)	4 (2)	17 (1)	5 (3)	14 (5)	5 (3)	8 (1)
Initial emissions (kgCO2eq)	63880	78040	63720	61240	57980	42300
Initial Gini	0,30	0,33	0,39	0,39	0,43	0,47

Développement et environnement	Société et environnement	Océan et climat	Dynamique de la Terre	Ressources en eau	Qualité de l'air
2 (1)	20 (4)	4 (0)	1 (0)	4 (1)	1 (0)
52840	67660	70320	44220	62920	44300
0,49	0,51	0,52	0,54	0,72	0,73

Table 1 : Number of workshops conducted in each research-team category (each colour represents one main research field and is conserved through all the manuscript), along with their initial carbon footprint and G coefficient at the beginning of the workshops. The data in brackets represent workshops that obtained extra funds (i.e. extra GHG) during the game.

The twelve virtual research teams presented in Table 1 are ordered by increasing G coefficient and are : technology and transition, international joint laboratory, environment, geophysics, informatics, computer science, climatology, development and environment, society and environment, ocean and climate, earth dynamics, water resources, and air

quality. These teams, and their names showing their main research focus, reflect part of the diversity of scientific fields and organisational structures found in the academic sector and were designed by scientists from these disciplines. Their specific GHG emissions and the degree of inequality of distribution are specific examples and have to be considered as so.

2. Final states

Were participants able to collectively reach the Paris agreement, and half their carbon footprint (H1, see section Materials and Methods III) ?

As reported in Figure 1, the workshops yielded substantial intentions of reductions across virtual teams, with reduction of GHG values ranging from 27% to 63%. The average final reduction is 44% and the median of 46%, close to the objective fixed at 50%. A majority of workshops (51 over 85) are also located in the 40-50% window. Interestingly, and surprisingly, no correlation is observed between GHG emissions reduction and final G coefficients (H2, see section Materials and Methods III.). The regression analysis shows a non-significant p-value and a high residual dispersion indicating the absence of a reliable relationship between the two variables. This result holds even looking for individual virtual teams only. If we now examine the pattern by research disciplines (i.e. clusters of coloured dots), we can observe a significant clustering vertically, but not horizontally. In other words, the degree of inequality, by virtual research teams, remains visible at the end of each workshop, but it does not influence the intention of GHG emission reductions. Although initial inequality levels vary widely between virtual research teams, with G values from 0,30 to 0,73 (see Table 1), they remain broadly constant during the game, so that intra-team G variation remains low (~0.05), while inter-team final G values range widely, from 0.21 to 0.74 for «technology and transition » (light brown dot) and « air quality » (purple dot) virtual teams, respectively.

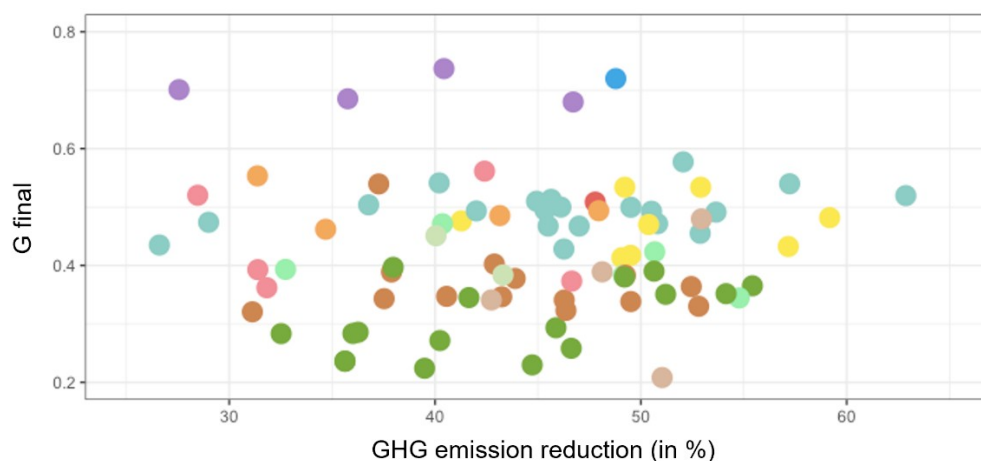


Figure 1 : Distribution of G coefficients with the reduction of GHG emissions during a workshop for the 12 different virtual teams (colour legend is reported in Table 1).

II Impact of initial equality level on collective interactions (H2)

In a second phase, we try to assess the possible impact of equality level at the beginning of the workshops onto deliberative processes and collaboration. Results are shown in Figure 2, which represent the variation of G values from the beginning (initial) to the end (final) of workshops. For the twelve virtual teams considered, the initial G values are fixed, but the final values depend on interaction between participants during the workshop. The final G indices closely align with the initial values across all virtual research teams, indicating that equality level remain, by mean, unchanged during the workshops. The degree of equality in the distributions is statistically stable, with a regression slope of 0,94, close to one ($y = 0,94x + 0,016$, $R^2 = 0,7289$). This implies that teams starting with higher initial inequality maintain relatively high inequality, and vice versa. Nevertheless, for teams with high equality at the beginning (techno and transition, international joint laboratory, geophysics), we can perceive a broader spreading of G values around the average, slightly in favour of decreasing the equality (clearer in Figure 3). In addition, the coefficient lower than 1 could indicate a trend to slightly increase the equality during workshops (see Figure 2).

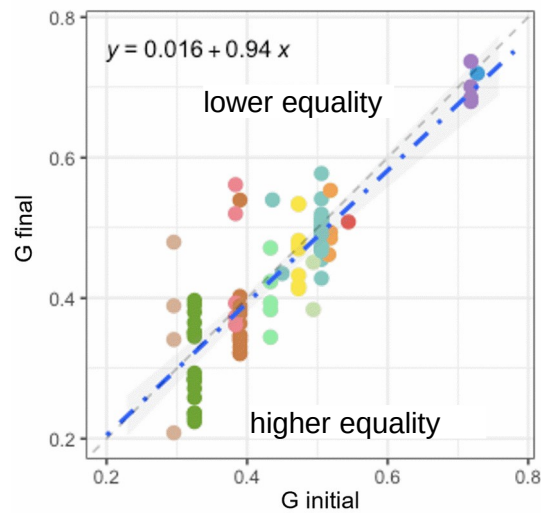


Figure 2 : Variation of G values at initial state versus G values at final state of all the workshops for the different virtual teams (colour legend is reported in Table 1). Passing under the grey one-one line indicates higher equality between the characters and conversely.

The trend is further clarified by plotting the relative change in the G coefficient as a function of its initial value, as reported in Figure 3. The figure shows the spread of points narrows as initial inequality increases, producing what we named a “pinching” effect. Analysis of the final versus initial G values indicates that teams with initially more equal distributions exhibit greater potential variations, whereas teams starting with higher initial inequality show less scope for change. This “pinching” effect was characterized by quantifying the standard deviation of each dots series. There is a clear decreasing trend of the standard deviation values (38, 19, 25, 15, 11, 9, 8, 8, 4) when increasing G initial values of the beige, green, pink, brown, cyan, yellow, blue, orange and purple data series reported in Figure 3.

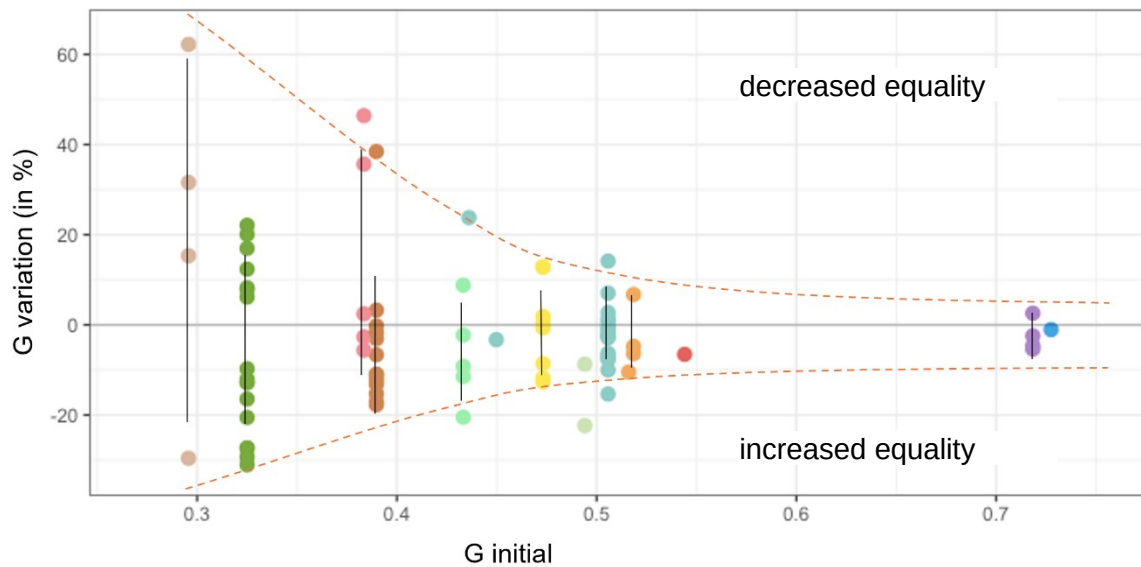


Figure 3 : Variations of G coefficient during workshops depending on initial G value (start of the workshop) and virtual teams considered (colour legend is reported in Table 1) showing larger possibilities of changes for virtual teams with low initial inequalities. The first group of teams (4 teams) strands with initial G values less than 0.4. The second group of teams (7 teams) stands between 0.4 and 0.6 initial G values and a last group higher than 0.6 is observed (note that this latest group - 2 teams - contains only 5 workshops).

III Impact of extra funding (H3)

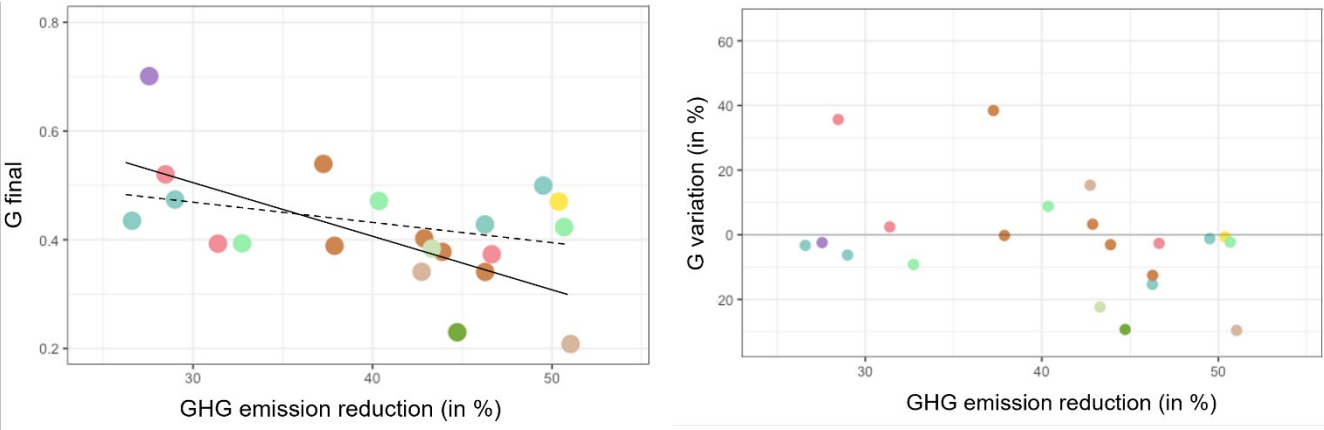
At the mid-term of negotiations, during *MTr* workshops, the participants have the opportunity to postulate to extra funding, with a rate of success of $\frac{1}{6}$, close to rate of success of first rank national and international research calls. The application of participants to extra funding is a voluntary action proposed by participants and accepted by the facilitator, according to the profile of characters and their potential to apply for funds in real life (e.g. impossibility of applications to certain grants for PhD students and administrative staff). The success and arrival of extra funding implies additional long and medium haul journeys for kick-off, intermediate and final meetings. In real life as in the game, this has some direct consequences on the carbon footprint. In *MTr*, the winner receives some extra + 4000 or + 8000 kgCO₂eq of GHG emissions, for national and international successful applications,

respectively. It directly and severely impacts the carbon footprint of the character, and the one of his research team.

As previously mentioned in Table 1, 21 workshops (among 85) won extra funding (one or two). This implies extra efforts to reach the -50% reduction target. On average, teams without additional funding achieved a carbon footprint reduction of -46.5% whereas teams with additional funding achieved -42.8%. As shown previously by [Gratiot et al., 2023], extra funding and associated carbon footprint should have mechanically led to an average reduction of -33.9% for the concerned workshops. This suggests that, while reductions are more challenging to achieve when extra resources are available, teams exert greater effort to reduce emissions under these conditions.

In the presence of national or international extra funding, a statistical correlation emerges between the magnitude of carbon footprint reduction and the final G coefficient across teams, as shown in Figure 4. A pattern that holds even when excluding the 3 extreme G values (see Figure 4, solid and dotted lines, respectively). Thus, following an opportunity event, the intensity of emission reduction is positively associated with reductions in inequality, which differs from the general result presented previously In the Figure 2.

An analysis of relative changes reveals that 15 over 21 of the workshops winners of call for project (i.e. around 71%) show a lower G coefficient at the end of workshops. However, this equality improvement could be small. Indeed, 13 over 21 (~ 62%) workshops have a percentage of evolution lower than 10%. Even if extra funding is stimulating new collaborative options, the social norm existing at the beginning of the workshop possibly remains a strong marker of the game, and influence participants to unconsciously go back to the initial degree of equality, by redistributing these extra funding.



238 *Figure 4: Absolute (left panel) and relative (right panel) variation of G with GHG emission reduction for*
239 *all workshops (21) with success of extra funding (colour legend is reported in Table 1).*

240 The distribution of opportunities was further examined according to character career stages
241 (junior versus senior). Meta data are reported in Table 2. Among 26 cases (from 21 research
242 teams winning projects, 5 workshops won 2 projects), around two-third of extra funding were
243 awarded to senior researchers (18 over 26) and 7 to junior researchers. Concerning senior
244 researchers, in around 78% of the cases (14 over 18), the G coefficient at the end of the
245 workshop decreased, which tends to show a "wake up" of awarded senior researchers
246 concerning equity. Indeed, when extra funding arrives, they perform more efforts to reduce
247 their carbon footprint compared to junior researchers, even if usually they have stronger
248 psychological profiles and are less inclined to GHG emission reductions.

	Junior	Undefined	Senior	Total
Higher Gini (lower equality)	4		4	8
Lower Gini (higher equality)	3	1	14	18
Total	7	1	18	26

249
250
251 *Table 2: Number of workshops with extra funding success (national or international funding, could be*
252 *one or two awards) distributed over junior and senior researchers, G evolution at the workshop end.*

Discussion

I Revisiting the hypotheses in light of the results

This game-based study explored how social norms or pressures [Lerner, 2023], collective targets, and external events influence researchers' attitudes, and intentions to reduce (e.g. justice motivation, [Lerner, 2023]) with fairness their carbon footprint. Specifically, it aimed at assessing whether initial inequality affects GHG emission reduction (hypothesis H1), whether the gamified environment helps decreasing emissions inequalities (hypothesis H2), and how sudden changes, such as extra-funding opportunities, influence both overall emissions and intra-team disparities (hypothesis H3).

The overall set of data gathered about five hundred participants distributed over 85 workshops. The study thus required a substantial logistical involvement, even if the *MTr* workshops can indifferently be realised by persons or by distance. While the analysis is robust at a general scale (including all virtual research teams), for inter-research team domains, it is statistically limited at intra-research team patterns, with a sample size capped at 20 games per virtual team family. The intra-research team analysis is thus limited to trend explorations and will require further validation with a larger dataset.

The results indicate that inequality within virtual teams, measured by the G coefficient, is not a determining factor in their capacity to reduce emissions. No significant correlation emerged between carbon-reduction performance and final G values, either across or within teams, suggesting that initial inequality does not predict mitigation outcomes. These findings highlight that even highly unequal teams were able to achieve as substantial reductions as more egalitarian teams. Teams with initially low inequality (egalitarian) encountered a wider range of scenarios and demonstrated greater flexibility in negotiating changes than those with higher initial inequality.

External funding opportunities revealed to have some dynamic effects on teams performance. Unsurprisingly, teams without additional resources showed the highest reductions. Their carbon footprint decreased by 46.5%, compared to 42.8% reduction for funded teams, although funded teams appeared to exert more effort. After funding events, a statistical correlation emerged between carbon reductions and final G values across teams, indicating that greater effort was associated with lower carbon budget disparities between characters. These results suggest the existence of favourable momentum for collective actions, so that well-timed interventions can enhance engagement and, in some instances, reduce disparities, highlighting the potential importance of synchronous dynamics between funding strategies and the incitations for environmental actions.

II Modelling vs. Reality : limits of the game and its metrics

While *MTr* provides a controlled and transparent game-based method to explore collective decision-making, it cannot fully capture the complexities of real-world contexts. In practice, outcomes in actual academic settings relating to travel or expatriation, particularly toward the Global South, are less shaped by environmental concerns than by personal constraints (childcare, health, espousal careers), interpersonal structures (social norms, academic culture), institutional structures (university policies, funding incentives, evaluation practices), and broader socio-demographic factors (gender and sexual orientation, professional status, family commitments, visa requirements, disability ; [Teran-Escobar et al., 2024]). Players' decisions are influenced by ideological positions, enjoyment of game mechanics, and their ability to embody assigned characters, factors that can outweigh fairness considerations. Moreover, the game cannot accurately reflect the broader context of inequity, its multidimensional nature, its structural, and historically embedded nature, its systemic complexity, or its far-reaching implications of real-world inequities.

Similarly, the G coefficient, while useful for summarising distributional inequality, has notable limitations [Lechthaler et al., 2025]. It measures equality in outcomes but not equality in

effort, resources, or opportunities. Consequently, relying solely on the G coefficient risks obscuring meaningful disparities and structural inequalities. To deepen the analysis, quantitative indicators should be complemented with tools that take into account normative dimensions, such as equity matrices or participatory assessments of fairness [Lechthaler et al., 2025], which help identify structural barriers and ethical considerations that statistical indicators alone cannot address. Such qualitative approaches could also prompt reflection on the values and purposes of research. In brief, there is a clear need for robust evaluations of the impacts of serious games for climate change mitigation [Hognon et al., 2026].

III How the findings interact with existing research

Comparing objective inequalities (e.g., the G coefficient) with perceived inequalities (i.e., what participants observe during the game) could offer valuable insights into behavioural dynamics [Gratiot et al., 2023]. Of course, the level of transparency and the visibility of inequalities shape how they are perceived. While previous research shows that visible economic disparities tend to reduce cooperation and heighten concerns about social status [Lechthaler et al., 2025], groups of participants in *MTr* were able to reduce emissions regardless of their initial (visible) disparities. These findings challenge the assumption that initial inequalities could constrain collective mitigation capacity (combined hypotheses H1 and H2). They suggest that collective targets, structured decision-making, and procedural transparency may buffer the negative behavioural effects of inequality typically observed in real-world contexts.

A second dimension concerns the interaction between the influence of high-status characters in the game and the actual hierarchical status of the participants embodying them. High socio-economic-status individuals are known to disproportionately contribute to climate change through consumption (particularly travel and housing), investments, symbolic influence, and organisational authority [Nielsen et al., 2021 ; Willis et al., 2022]. In *MTr*, this raises the hypothesis that senior researchers may exert similar clout over group decisions,

resource allocation, or cultural norms, potentially enabling or constraining mitigation efforts,
an aspect that warrants empirical investigation.

A third-dimension relates to how inequality is conceptualised [Lechthaler et al., 2025].
Viewing wealth as accumulated emissions over time, rather than as an instantaneous
footprint, may provide a more nuanced interpretation of both inequalities and mitigation
opportunities. Visualising emission trajectories could support more informed discussions
around effort distribution, quota allocation, and fair responsibility-sharing among team
members.

From a qualitative perspective, it would therefore be essential to begin by examining pre-
existing inequities within laboratories and between partners, particularly in collaborations
with the Global South. In such contexts, disparities in resources, mobility, wages, and
political stability often generate structural asymmetries and even brain drain [Coutellec et al.,
2024]. One possible approach would be to apply GHG reduction constraints to partners in
the Global North without imposing them directly (or indirectly) on Global South researchers.
Based on an initial assessment of inequities, teams could then collectively define how
funding or additional resources should be allocated. In this regard, *Ma Terre* offers an
opportunity to analyse how participants perceive initial and final inequities, how they interpret
them, and how they adapt their behaviour during the workshop in response to perceived
disparities. Comparing objective inequality, measured via the G coefficient, or equity by
including social justice such as help of networking for young researchers or developing
Global South research independence, with subjective perceptions could substantially enrich
this analysis.

Conclusion

Integrating gamified experiences with tools capturing normative dimensions of equality offers a promising pathway to support sustainable and fair practices in academic research. This underscores the need to combine gamified approaches with reflective discussions on perceived fairness, initial disparities and with institutional measures, such as flight quotas, revised funding and researcher evaluation criteria, and adjusted incentive structures, to support both emission reductions and equity in academic research. Furthermore, gamified approaches proved effective in fostering engagement and intentions to change, highlighting the central role of motivations, capacities, and opportunities in shaping behaviour.

Our study results from 85 workshops focused on travel-related emissions and gathered five hundred participants, where collective dynamics were assessed on the ability of participants to achieve a 50% emission-reduction target in a game-based online platform. *Ma Terre* workshops demonstrated that participants were able to develop reduction scenarios close to the target (~45%) and reach consensus on high-impact actions. Nevertheless, ambitious mitigation targets did not systematically translate into improved equality or social justice outcomes, so that Gini coefficient was in general not correlated with carbon footprint reduction. A specific situation counterbalance this pattern, when external resources and interventions can create specific momentum for actions that both enhance mitigation efforts and reduce disparities (~ 71%).

As a general conclusion, the transition toward socio-ecological academic research practices requires addressing both environmental impacts and social justice through equity principles: democratic environments and lower inequality levels encouraged open reflection and collaboration, while windows of opportunity provided critical momentum for collective action. At the same time, translating intentions into sustained behavioural change remains a key challenge and a clear perspective for further works.

Some recommendations for practical evolution of scientists' behaviour can be addressed. Firstly, the targets to be achieved must be quantified and made visible. In the workshops conducted, the G coefficient and its evolution were not known to the participants. It was visually present through the surface area of the tokens assigned to each character, but was not shared displayed (i.e. the Gini coefficient and its evolution throughout the game was not shown). At the opposite the dynamic display of the GHG emissions, and the fact that a target had been set (- 50% of emission reduction) undoubtedly influenced the participants' decisions, without fully considering the possible injustices and how to reduce them. Secondly, there are significant social norms working to maintain the status quo. Professional habits and underlying inequities are robust and difficult to challenge. Pathways conducive to change can operate, particularly when an external event occurs. In our case, this was the positive response to a call for projects. Without a rebalancing mechanism, calls for projects are statistically more likely to be awarded to senior researchers, whose environmental footprint is already much greater than early careers. This mechanically increases inequities rather than reducing them. To maximise the impact of external events in promoting greater equity, calls for proposals should scope applicants from the lower Lorenz curve section. This would promote the reduction of inequities, even if social counterbalancing forces will diminish the expected effect.

Future research could focus on pre-workshop assessments to identify initial inequities and develop longer-term visions of research-related carbon footprints, as well as post-workshop evaluations of perceived fairness and effort distribution. Integrating visualisation tools such as Lorenz curves could enhance awareness of inequalities during negotiations. Further work could also examine procedural equity in negotiation dynamics, including the equality of voice, to better understand how decision-making processes influence both carbon reductions and distributive outcomes. Overall, these findings suggest that advancing environmental sustainability and social equity in academic research will require meaningful innovations, particularly mechanisms that create opportunities and effectively motivate participants to

403 exert additional effort. Ultimately, the challenge lies in striking an appropriate balance
404 between reducing the carbon footprint of research activities and preserving the positive
405 contributions of research to environmental knowledge and broader societal benefits.

406

Materials and Methods

I Protocol, data collection and experimental procedure

The methodological framework of *Ma Terre* workshops has been fully detailed by Gratiot et al., 2023 [Gratiot et al., 2023], therefore, only its main features are summarised here.

Each workshop begins with a shared scientific overview of climate change, outlining its causes, impacts, and implications for the academic sector. Participants are then collectively assigned the challenge of reducing the carbon footprint of their fictional research team by 50%. To support this process, each participant adopts a fictional character defined by attributes such as professional status, research activity profile, career stage, gender, transition psychological position (e.g. engaged in ecological positive activities or not inclined to perform efforts), and baseline carbon-intensive practices. This role-playing mechanism allows participants to simulate the functioning of a research team and negotiate carbon reduction strategies while preserving overall research performance.

MTr provides a structured participatory framework in which players identify and debate individual and collective mitigation options across key domains of academic work, including travel, fieldwork, conferences, computing, and the use of specialised scientific equipment. Although the tool underscores the significant contribution of air travel to academic GHG emissions, it also accounts for other transportation modes (train, car, boat for oceanographic surveys) and additional sources of emission such as numerical simulations and access to advanced scientific instruments (e.g., particle colliders). For the purpose of this study, the analysis focuses specifically on travel-related measures that participants indicate they are willing to adopt.

A full *MTr* session lasts 180 minutes, plus a 30-minute debrief. The dataset analysed here derives from 85 *Ma Terre* workshops, each involving approximately ten participants.

Workshops are distributed across twelve categories of fictitious research teams that are fully described in [Gratiot et al., 2023].

II Initial hypotheses

For this study, it is hypothesised that gamification, the establishment of collective targets and the activation of social norms or pressures, based on the “Doughnut” theory [Raworth, 2017], will:

(H1) *Increase participants’ willingness to reduce their environmental footprint, in terms of GHG emissions, regardless of the initial level of equality, in order to reach Paris’ agreement about climate change ;*

(H2) *Influence the distribution of GHG emissions among individuals, presumably reducing inequality regardless of the scientific community and of its research practices, trying to follow equity principles during environmental transition ;*

(H3) *Be influenced by the occurrence of an external event, such as a new funded project ; this latter raises the difficulty of reducing the carbon footprint and reinforces inequities. Practically a new project means additional travels and seniors are more likely to obtain substantial funds than juniors. This hypothesis is considered as hazard effects on social momentum.*

These three hypotheses are conceptually sketched in Figure 5 and will organize the presentation of result and discussion sections.

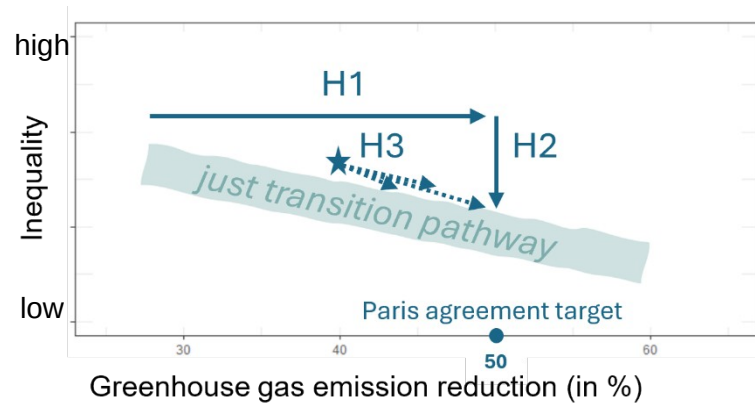


Figure 5 : Conceptual sketch of the three hypotheses and their potential effect for a just transition pathway. The blue horizontal and vertical solid line arrows represent hypotheses H1 and H2, respectively ; the blue star represents the success in a call for proposal ; the dotted blue lines represent the resulting additional efforts to go through a just transition pathway (green line).

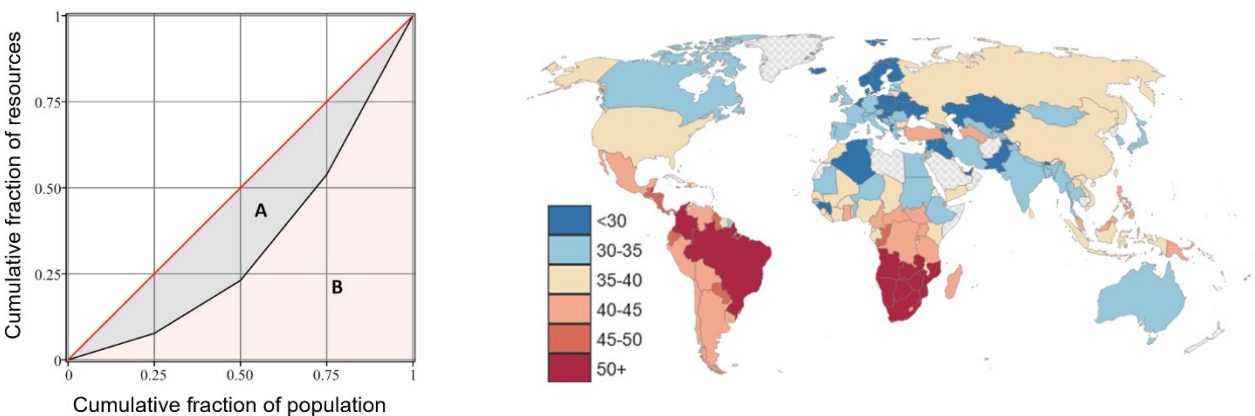
III Analysis method

The Gini coefficient (G) is a statistical indicator commonly used to quantify the degree of inequality within a distribution, most often in the context of income or wealth [Yitzhaki et al., 2013 ; Haddad et al., 2024 ; Lechthaler et al., 2025]. Its value ranges from 0, indicating perfect equality where all individuals possess the same amount, to 1, representing maximal inequality where a single individual holds all resources. The concept is straightforward both in its mathematical formulation and in its graphical interpretation in Figure 6.

The computation of G relies on the Lorenz curve (Fig. 6a). This curve plots the cumulative fraction of the population on the x-axis against the cumulative fraction of the resource on the y-axis. The red line represents perfect equality ($y=x$), while the Lorenz black curve depicts the empirical distribution. The G coefficient is defined as the ratio between the area lying between the line of perfect equality and the Lorenz curve (area A) and the total area under the line of equality ($A + B$). By quantifying this relative area, the G coefficient provides a synthetic measure of how far the empirical distribution deviates from perfect equality.

$$G = A / (A+B) \quad (1)$$

471 The countries by level of economic inequality, according to the World Bank in 2024 is
472 reported in Figure 6b, for illustration purposes.



473 *Figure 6 : a. Illustration of Gini's computing, from the Lorenz curve (black line), [Lechthaler et al.,*
474 *2025]. b. Countries by Gini coefficient in 2024, Worldbank, Poverty and Inequality Platform.*

475 During the workshops, G is calculated at the initial stage, using the initial carbon footprints
476 distribution between characters. As an illustration, the distribution of GHG emissions by
477 characters is presented in Table 3 for two contrasted virtual research teams, namely the
478 « International joint laboratory » and the « Air quality »research teams. The corresponding
479 Lorenz curves and Gini's values are presented in Figure 7.

480 **International Joint Laboratory**

Isabelle	Hummingbird		Manager	40
Vinh	What for	Junior	Technician	3000
Léo	Concerned	Junior	PhD student	4000
Huan	Hummingbird	Junior	PhD student	5000
Antoine	Hummingbird	Senior	Engineer	8000
Lamaï	Concerned	Junior	Postdoctoral	9000
Danh	What for ?		Invited professor	9500
Florence	Activist	Junior	Researcher	12000
Corinne	I make the difference	Senior	Full professor	13500
Romain	What for ?	Senior	Researcher	14000

481

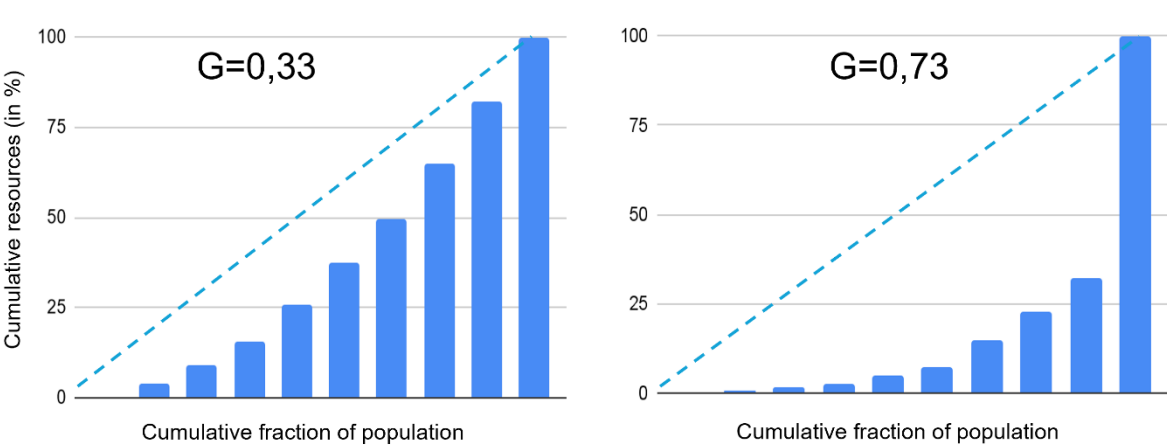
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Air Quality Research Lab

Charlie	Activist	Senior	Researcher	40
Daisy	What for ?	Senior	Professor	240
Jeff	I make the difference	Senior	Researcher	360
Cornelia	Activist	Junior	PhD student	500
Yolanda	Hummingbird	Junior	Postdoctoral	940
Hilda	Hummingbird	Junior	PhD student	1040
Karl	Concerned	Senior	Teacher	3500
Joelle	Concerned	Junior	PhD student	3500
Will	Hummingbird	Junior	Engineer	4040
Fastolph	I make the difference	Senior	Reseacher	30140

483

484 Table 3 : Distribution of GHG emissions (in kgCO2eq), psychological character, career stage and
485 status by characters for two virtual research teams.



486

487 Figure 7 : graphical Lorenz curves and associated Gini's values for "International Joint Laboratory"
488 (left) and "Air Quality Research Lab" (right) virtual research teams.

489 IV Criteria for selecting method

490 The combination of *Ma Terre* gamified workshops and the G coefficient integrated statistical
491 parameter was chosen for its relevance, originality, and interpretability: *MTr* allows realistic,
492 participatory simulation of academic activities, capturing intentions ; the G coefficient

provides a synthetic measure of inequality, enabling comparison across teams of different size and initial degree of inequality ; graphical Lorenz curves complement the G coefficient by revealing structural differences in distributions.

This methodological approach directly addresses the study's objectives of assessing both carbon reduction intentions and distributional fairness within research teams, supporting insights into sustainable and just academic transitions. The analysis focus on identifying underlying trends and correlations through appropriate regression modelling.

Note about the terminology: whereas Gini coefficient represents the inequality within a distribution, we use sometimes in the manuscript the term inequity when it make sense, i.e. when it includes the justice social with the author position. It could for example reflect the incorporation of more possibilities for networking for young scientists or the less financial and human resources in the Global South.

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References

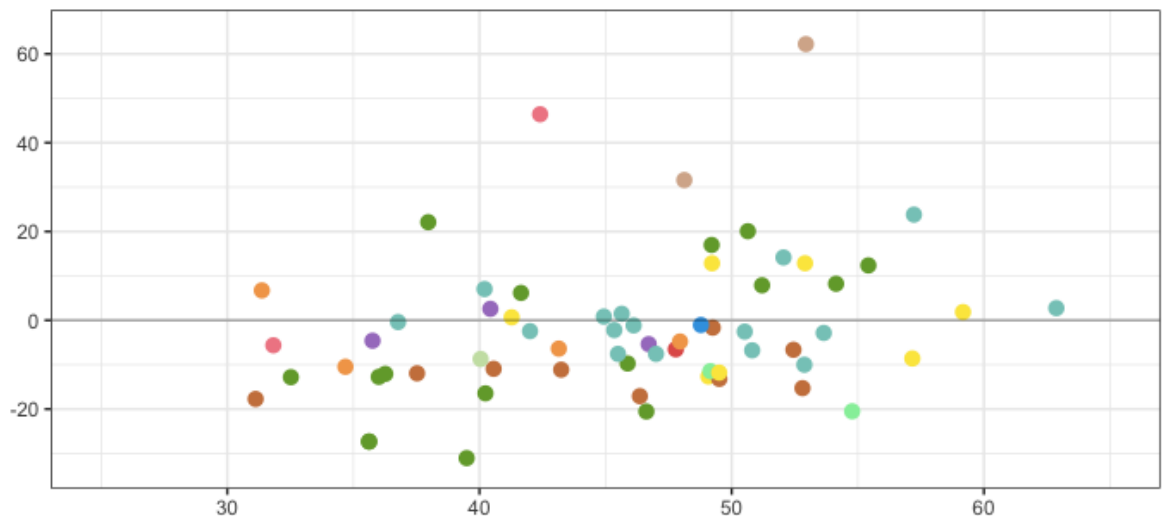
- 1 **Gratiot N. et al (2023).** A transition support system to build decarbonization scenarios in the academic community. *PLOS Sustain Transform*, 2(3): e0000049. <https://doi.org/10.1371/journal.pstr.0000049>
- 2 **Masson-Delmotte V. et al (2018).** Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming, 1 (5), pages 43-50. <https://doi.org/10.1017/9781009157940>
- 3 **Poupaud M. et al (2025).** Diversité des points de vue face à l'empreinte carbone de la recherche en partenariat avec les Suds. *Nat Sci Sociétés*, 33(1), pages 80-8. <https://doi.org/10.1051/nss/2025028>
- 4 **Berné O. et al (2022).** The carbon footprint of scientific visibility, *Environmental Research Letters*, 17(12):124008. <https://doi.org/10.1088/1748-9326/ac9b5>
- 5 **Hardy A. et Noûs C (2023).** Quantifier la frugalité de la recherche ?, *Socio*, 17, pages 83-117. <https://doi.org/10.4000/socio.14157>.
- 6 **Marc O. et al (2024).** Comprehensive carbon footprint of Earth, environmental and space science laboratories: Implications for sustainable scientific practice. *PLOS Sustainability and Transformation*, 3(10): e0000135. <https://doi.org/10.1371/journal.pstr.0000135>
- 7 **Gokus A. et al. (2024).** Astronomy's climate emissions: Global travel to scientific meetings in 2019. *PNAS nexus*, 3(5), pages 143. <https://doi.org/10.1093/pnasnexus/pgae143>
- 8 **Corneyllie A. et al (2025).** Doing conferences differently: A decentralised multi-hub approach for ecological and social sustainability, *PLOS Sustain Transform*, 4(6): e0000177. <https://doi.org/10.1371/journal.pstr.0000177>

- 9 **Moraru A. et al (2024).** Polar fieldwork in the 21st century: early career researchers considerations regarding safety and sustainability, *PLoS Climate*, 3(7), e0000415. <https://doi.org/10.1371/journal.pclm.0000415>
- 10 **Blanchard M. et al (2022).** Concerned yet polluting: a survey on French research personnel and climate change, *PLOS Climate*, 1(9): e0000070. <https://doi.org/10.1371/journal.pclm.0000070>
- 11 **Institut de Recherche pour le Développement (IRD, 2024).** Bilan des émissions de gaz à effet de serre de l'IRD. <https://www.ird.fr/bilan-des-emissions-de-gaz-effet-de-serre-de-lird>
- 12 **Millward-Hopkins J. et al. (2022).** Why the impacts of climate change may make us less likely to reduce emissions. *Glob Sustain*, 5:e21. <https://doi.org/10.1017/sus.2022.20>
- 13 **Daggett C. (2018).** Petro-masculinity: Fossil Fuels and Authoritarian Desire, *Sage journals*, 47(1). <https://doi.org/10.1177/0305829818775817>
- 14 **Fanchette S. et al (2024).** The ambivalence of low carbon research with partners in the Global South. ISBN 978-2-7099-3041-3
- 15 **Baxerres C. (2023).** Empreinte carbone de la recherche : quand les injonctions venant d'« en haut » sont contreproductives, comment se (re)mobiliser pour d'indispensables actions ? *Anthropol Santé*, 27. <https://doi.org/10.4000/anthropologiesante.13083>
- 16 **Ben-Ari T. (2023).** How research can steer academia towards a low-carbon future. *Nat Rev Phys*. 5:551-2, <https://doi.org/10.1038/s42254-023-00633-9>
- 17 **Ma Terre.** *Ma Terre – Serious Game*. <https://materre.osug.fr/>

- 18 **Lechthaler B. et al. (2020).** Objective homogeneity quantification of a periodic surface using the Gini coefficient. *Scientific reports*, 10(1), 14516. <https://www.nature.com/articles/s41598-020-70758-9>
- 19 **Lerner M.J. (2023).** Confusing the Expression of Social Norms and Justice Motivation. *Soc Just Res* 36, pages 325–335. <https://doi.org/10.1007/s11211-023-00415-9>
- 20 **Teran-Escobar C. et al. (2024).** A pilot randomised controlled trial comparing the effectiveness of the MaTerre180' participatory tool including a serious game versus an intervention including carbon footprint awareness-raising on behaviours among academia members in France, *PLOS one*. <https://doi.org/10.1371/journal.pone.0301124>
- 21 **Hognon L. et al. (202.).** A call for robust evaluations of the impacts of serious games for climate change mitigation: The Climate Fresk as a global case study. *Journal of Environmental Psychology*, 102942.
- 22 **Willis G.B. et al (2022).** The psychosocial effects of economic inequality depend on its perception. *Nat Rev Psychol*, 1(5), pages 301-309. <https://doi.org/10.1038/s44159-022-00044-0>
- 23 **Nielsen K.S. et al. (2021).** The role of high-socioeconomic-status people in locking in or rapidly reducing energy-driven greenhouse gas emissions. *Nat Energy*, 6(11), pages 1011-1016. <https://doi.org/10.1038/s41560-021-00900-y>
- 24 **Coutellec L. et Jean K. (2024).** La bifurcation écologique de la recherche scientifique : une nécessité éthique et politique. *Natures Sci Sociétés*. 32(1), pages 1-2. <https://doi.org/10.1051/nss/2024030>

629 25 **Raworth, K. (2017).** A Doughnut for the Anthropocene: humanity's compass in the 21st
630 century, *The Lancet Planetary Health*. [https://doi.org/10.1016/S2542-5196\(17\)30028-1](https://doi.org/10.1016/S2542-5196(17)30028-1)
631
632 26 **Yitzhaki et al. (2013).** [https://books.google.fr/books?](https://books.google.fr/books?hl=fr&lr=&id=_9lVaJMwmaUC&oi=fnd&pg=PR7&ots=qphavtUKW3&sig=bsX9PR-wUEZSHtRatTdeb7eQMpu&redir_esc=y#v=onepage&q&f=false)
633 [hl=fr&lr=&id=_9lVaJMwmaUC&oi=fnd&pg=PR7&ots=qphavtUKW3&sig=bsX9PR-](https://books.google.fr/books?hl=fr&lr=&id=_9lVaJMwmaUC&oi=fnd&pg=PR7&ots=qphavtUKW3&sig=bsX9PR-wUEZSHtRatTdeb7eQMpu&redir_esc=y#v=onepage&q&f=false)
634 [wUEZSHtRatTdeb7eQMpu&redir_esc=y#v=onepage&q&f=false](https://books.google.fr/books?hl=fr&lr=&id=_9lVaJMwmaUC&oi=fnd&pg=PR7&ots=qphavtUKW3&sig=bsX9PR-wUEZSHtRatTdeb7eQMpu&redir_esc=y#v=onepage&q&f=false)
635
636 27 **Haddad C. N. et al. (2024).** The World Bank's New Inequality Indicator. *Policy Research*
637 *working paper no. WPS, 10796.*
638

639 **Supplementary materials**



640
641 *Figure S1: variations of G coefficient (in %) at the end of the workshop function of GHG emission*
642 *reduction (in %) for all the workshops that did not succeed at extra funding for the 12 different teams*
643 *(colour legend is reported in Table 1).*