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Multidisciplinary science funding is more than ever a planetary priority: Reflections from the Make Our Planet Great Again (MOPGA) program

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Abstract

Global change poses "wicked problems" that have become ever more complex, pervasive, and damaging. Developing innovative solutions increasingly require diverse research approaches. The Franco-German *Make Our Planet Great Again* (MOPGA) program was designed to create a unique international network of top-level research, from fundamental to solution-oriented projects. MOPGA stands out from other large research initiatives by focusing not on a singular central research challenge but on facilitating multidisciplinary interactions between traditionally separated fields. MOPGA recognized that social, natural and engineering sciences share a unifying aim to address global change. In addition to addressing timely and innovative research questions within disciplines, MOPGA worked to improve communication across disciplines via annual meetings for all laureates and their research groups, scientific board exchanges, and public online seminars. Drawing on our MOPGA experiences, we discuss how such exchanges should be extended to meet the needs identified by the scientific community, international policy-makers, and regional stakeholders. In the current political landscape of scientific suppression and heightened mistrust in scientific expertise, the need for such bold, independent and collaborative scientific initiatives is greater than ever.

Introduction

Global change - including climate disruption, biodiversity loss, energy transitions, resource depletion, pollution - poses some of the most urgent and complex challenges of our time. Yet the political landscape surrounding science has never been more fraught. The *Make Our Planet Great Again* (MOPGA) initiative was launched in 2017 as a direct response to the first Trump administration's decision to withdraw from the Paris Agreement and roll back climate and environmental research funding. Spearheaded by French President Emmanuel Macron and later embraced by German Chancellor Angela Merkel, MOPGA was not just a research program. MOPGA was a statement and an exceptional international research opportunity for scientists from the United States and the rest of the world. The program provided a platform for world-class research across disciplines, emphasizing transnational collaboration on global change.

Today, as the second Trump administration ushers in a wave of scientific suppression - scrubbing climate and environmental data from government websites, freezing funding for climate-related research, and attempting to drive top scientists out of agencies like NOAA, EPA and NASA - the legacy of MOPGA is more relevant than ever. The program's conclusion coincides with a period of heightened mistrust in scientific expertise where political interference is once again stifling not only climate action but also research on biodiversity, energy systems, pollution mitigation, and resource sustainability.

History has shown that international programs that welcome scientists - including those facing political or institutional barriers in their home countries - are a powerful way to support science and sustain scientific progress during periods of contracting funding [1]. By providing research opportunities for researchers and funding critical studies on the interconnected crises of global change, initiatives like MOPGA help maintain the continuity of scientific knowledge, prevent brain drain from the global community, and ensure that evidence-based solutions remain at the forefront of international policy discussions. As the world grapples with intensifying environmental and resource challenges, MOPGA serves as both a model for what is possible when science is championed at the highest levels and a stark reminder of the fragility of research environments under populist governance.

Here we examine the accomplishments of MOPGA, distilling lessons learned from its multidisciplinary approach to global change science. Climate change is one of the central global challenges facing our time. The evidence on its anthropogenic causes is beyond doubt and based on sound science. Climate scientists have invested a huge effort to understand and accurately quantify the multidimensional feedbacks occurring at the interfaces of the different components of the Earth's systems. Considerable increases in computational power over the last decades have allowed for more accurate climate models that account for complex feedback mechanisms between the atmosphere, land surfaces, the ocean and the biosphere [2]. Several reports of the Intergovernmental Panel on Climate Change (IPCC) established the physical science of climate change, reviewed impacts and assessed adaptation options and mitigation pathways. The impacts on biodiversity and the world's ecosystems, the effects on human health and well-being, and the implications for climate and energy justice are being explored. Scientific frontiers are being pushed further, for example to include assessing the impacts on carbon storage of natural and managed ecosystems. Disciplinary boundaries, which have long siloed scientific conversations, are being broken down, giving way to increasingly cross-, inter- and transdisciplinary approaches. The development of sound, effective and feasible actions still requires both increased scientific studies to better quantify key processes as well as a high level of interdisciplinary communication to ensure that these specific needs are conveyed across disciplines [3–5]. Yet, the primary limitation to addressing the challenges of global change is not the generation of scientific knowledge. Two major obstacles lie elsewhere: structural constraints and political interference.

First, structural challenges arise from the design of global climate governance. The Paris Agreement in 2015 marked a shift toward a more global strategy based on voluntary contributions of individual countries, emphasizing the need for an integrated approach across ecological, technical, social, economic, and political dimensions. The Paris Agreement also demanded a shift in commitment to combating climate change. However, developing effective global solutions has been hampered by traditional avenues for research funding that are largely within individual nations. Truly international efforts, aimed at matching the brightest minds with sufficient funding opportunities, are scarce.

Second, political obstacles pose additional challenges as climate science has come under threat from populist leaders around the world, running on nativist and science-denying electoral platforms. President Donald Trump withdrawing from the Paris Agreement in 2017 and again in 2025, epitomized such a climate-isolationist agenda on the part of the US government, including funding cuts for climate change related programs and beyond, and disabling public access to relevant data.

The MOPGA program was meant to send the clear signal that continued climate research is crucial to address one of the world's current biggest challenges. It also strengthened truly international research on the complex problems of not just climate change but global changes more generally. The program was designed by the French National Center for Scientific Research (CNRS), the French National Research Agency (ANR) and the German Academic Exchange Service (DAAD) to identify mitigation and adaptation strategies laid out in the Sustainable Development Goals of the United Nations. The program aimed to achieve this goal by funding excellent science related to global environmental problems and fostering increased international and multidisciplinary cooperation by attracting scientists living outside of France and Germany at that time. In fact, the original MOPGA call explicitly stated that the program was restricted to researchers who had not resided in France or Germany for at least the two years preceding the call deadline. As such, MOPGA provided a unique opportunity to gain a snapshot of the diversity of global change-related research that spans the goals of the different working groups of IPCC. Importantly, the program supported cross-talk among the relevant disciplines. The group consisted of 53 scientists from 17 countries, who carried out studies based in France and Germany for 3-5 years. Broadly, the projects aimed to address three main objectives: (1) improve our understanding of the processes, (2) quantify the impacts, and (3) explore solutions to the challenges of anthropogenic global change. Across these objectives, projects addressed one or more of 17 interconnected research areas to work towards a just and peaceful resolution to the challenges of global change (Fig 1; S2 Table).

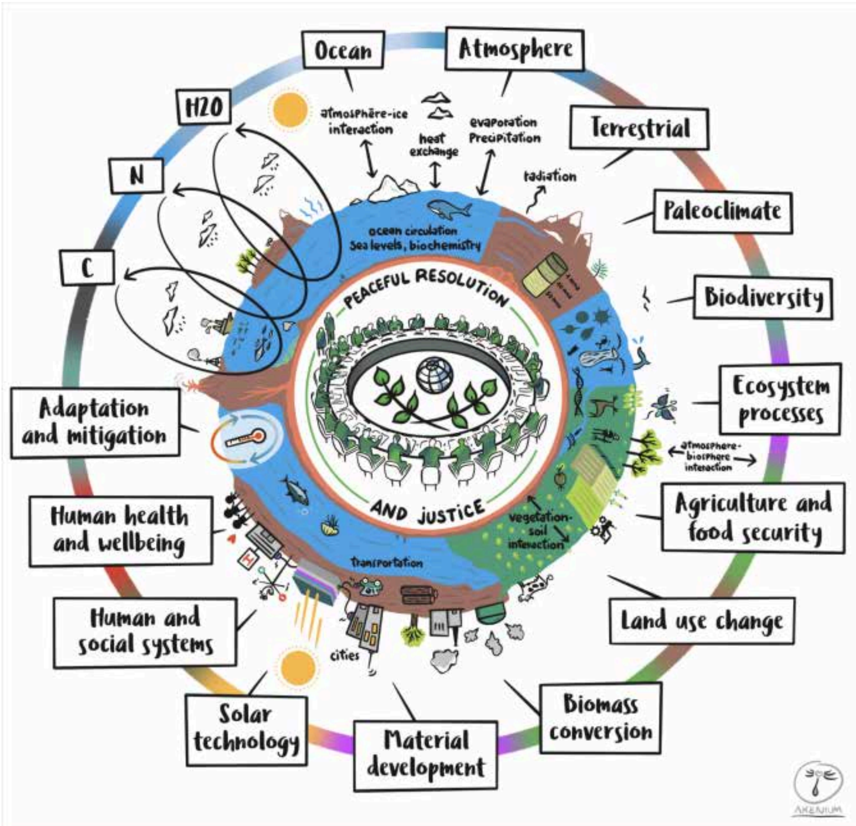

Fig 1. Overview of the MOPGA program highlighting 17 interconnected research areas supported across 53 projects with the ultimate aim to work towards peace, resolution and justice in the face of global change (S1 Table).

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An important aspect of MOPGA is that the program funded research across disciplines through an open call. Its scope was broad, leaving it to scientists to propose the topics they found most pressing to address, within the areas of the Earth system, climate change and energy transition. The call allowed for projects from the full spectrum of curiosity-driven science, not limited by political or ideological agendas. It explicitly targeted excellent international scholars, aiming to attract them long-term, and made their proposals subject to a rigorous review process. In addition, although the program directly funded individual research groups, venues were created to foster interaction between MOPGA laureates. MOPGA catalyzed multidisciplinary exchange through regular meetings and events. With logistical support from the funding agencies, a scientific board composed of MOPGA laureates actively developed and created the formats and platforms for scientific discourse, including public seminars, online discussions, and annual scientific in-person meetings. These efforts led to opportunities for scientific interactions and interdisciplinary exchanges that were unique to the MOPGA community. Below, we synthesize the work of the three main lenses represented in the MOPGA groups (see the full description of the MOPGA projects in S1 Text, S2 Text and S3 Text). We then discuss the next steps for moving from the multi-disciplinary toward achieving inter- and transdisciplinary approaches to the multifaceted challenges of global change.

Understanding processes of global change

A better understanding of the Earth system and its dynamics enables the development of more accurate climate models, improving our ability to predict future climate scenarios and assess their impacts on society, the economy and the environment, and ultimately working towards a more sustainable and resilient future. This is essential not only for predicting and mitigating the impacts of climate change, including extreme weather events, sea level rise, and shifts in ecosystems, but also for identifying its drivers, whether natural or anthropogenic. To contribute to this challenge, the MOPGA program included investigations and modeling of processes across multiple scales in time and space (Table 1).

Trends based on past climate

Although human activities have dramatically accelerated climate change in the recent past, the present-day dynamics of ecosystems and global climate are also complex products of a long history of geological activity. Obtaining knowledge of past climates and ecosystems to understand our current state and predict its future evolution has thus been a constant imperative of global change research [2,6,7]. Geological records show that there have been a number of large fluctuations in the Earth's climate since the origin of the planet, caused by many natural factors, including astronomical changes, emissions from volcanoes, and biological feedbacks. Several MOPGA projects have contributed to understanding this history and obtaining insight into modern climate dynamics by combining reconstructions using paleo proxies measured in natural climate archives (e.g., sediments, ice) with fossils that record ancient environments in their remains. MOPGA efforts provide evidence of past climate change as far back as 37 Ma (million years ago).

Connecting processes from molecular to global scales

Understanding the current climate requires accurate measures of the composition of all components of the Earth system, including the atmosphere, which impacts surface temperatures, biogeochemical cycles, and air quality on local to global scales. The particulate matter suspended in the atmosphere or 'aerosol particles' absorb or scatter radiation affecting the global energy budget ('aerosol direct effect'). Such aerosol particles may also act as condensation nuclei for cloud droplets ('aerosol indirect effect'), which reflect radiation and modulate Earth's hydrological cycle. The high spatial and temporal variability of aerosol particles, their effects on global temperature, biogeochemical cycles, and air quality are challenging to assess and form the core research of several MOPGA projects. Other projects contributed to scale differences by focusing on ocean circulation on various spatial scales or on paleoenvironmental climate archives over long temporal scales.

Table 1. Topics covered in MOPGA projects focused on Understanding Processes of Global Change (for key findings and references see S1 Text; project numbers in S1 Table).

Trends based on past climate [Projects 1, 4, 7, 18, 49, 52]	Connecting processes from molecular to global scales [Projects 6, 15, 27, 33, 41,44, 45, 51]	New challenges for Earth system modeling and forecasting [Projects 2, 5, 13, 14, 16, 17, 22, 28, 30]
• Use of natural, paleoenvironmental climate archives (sediments, ice) spanning the Cenozoic era	• The role of aerosol-cloud interactions on the radiation budget above the Southern Ocean and in the Arctic	• Large scale patterns of turbulence and the Atlantic Meridional Overturning Circulation (AMOC) in the North Atlantic and Arctic, El Niño Southern Oscillation (ENSO) spatiotemporal complexity, and the South American Monsoon System
• Past and predicted future plankton responses to changes in carbon (CO_2) levels and consequences on carbon capture	• Microorganisms in the atmosphere and micro/macroorganisms in the oceans affecting composition and biogeochemical cycles	• Forest-atmosphere feedbacks and changes in precipitation patterns in Amazonia and watersheds
• Impacts of long-term fluctuations of greenhouse gasses on ocean, glaciers, permafrost, and global sea level change	• Air quality downwind of Paris and in several cities across Sub-Saharan Africa to elucidate and mitigate sources of aerosol particles	• Development of surrogate models/parameterization using different approaches, including machine learning and big data sampling, with low computational costs for global change projections on different scales and mitigation scenarios

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New challenges for Earth system modeling and forecasting

Connecting processes from molecular to global scales across time requires models that can simulate the complex interconnections among Earth's atmosphere, hydrosphere, cryosphere, and land surface processes in the biosphere. Several MOPGA projects developed new tools and strategies to overcome the fundamental theoretical and methodological challenges of Earth System models (ESMs), from the better characterization of boundary-layer physics to improving the representation of large-scale phenomena. The MOPGA initiative contributed to two complementary paths that address the many challenges faced by today's ESMs. One is increased realism by resolving small-scale processes that currently cannot be simulated explicitly. The other is reducing complexity to the most essential processes.

Impacts of global change

Global changes have already had important impacts on ecosystems as well as human societies, and the two are intricately interlinked [4,8,9]. Functioning natural ecosystems provide a tremendous array of nature's contributions to people globally. A healthy, biodiverse ecosystem contributes to human health through clean air, water storage and filtration, removal and long-term storage of carbon from the atmosphere. Healthy ecosystems provide products for local consumption and export (e.g. food, timber, textile fibers, and medicines), and support local livelihoods and recreational activities [10,11]. Nature is also important for cultural reasons, playing a role in individual and group identity as well as in spiritual aspects and religious ceremonies [10,12,13]. The MOPGA program included diverse investigations to contribute to our understanding of the impacts of global change on natural ecosystems and human health and well-being (Table 2).

Impacts on biodiversity and ecosystems

Maintaining the benefits and integrity of ecosystems requires an understanding of how they function and how they will respond to the challenges of global change [14]. Ecosystems are dynamic and can be resilient to low levels of environmental change [15]. However, the current magnitude of human impacts, particularly related to climate change, risks pushing ecosystems, and the species within them, beyond critical thresholds from which they cannot recover in the foreseeable future [16,17]. MOPGA projects have advanced our understanding of the complex interactions between species and their environments through studies of a variety of plants, animals, and microbes across diverse terrestrial and marine habitats. These studies underscored how this work has always been challenging particularly because the distributions of species and their interactions with other species and environmental factors are nonlinear, dynamic, and complex [18]. In fact, it remains unclear whether species abundances are ever in equilibrium with the environment [19]. Furthermore, our understanding of how most traits are constructed or how they will change and evolve in response to the intensifying selection that characterizes global change remains limited [20–22].

Table 2. **Topics covered in MOPGA projects focused on impacts of Global Change (for key findings and references see S2 Text); project numbers in S1 Table.**

Impacts on biodiversity and ecosystems [Projects 3, 11, 12, 29, 32, 35, 43]	Impacts on human health and well-being [Projects 21, 23, 31, 32, 34, 35, 36, 39, 41, 48, 50]
• Complexity in ecosystem functioning due to changes in trait diversity and invasive species on land and in the ocean	• Inequalities across gender, countries and societies in cost distributions for mitigation and adaptation strategies
• Ecosystem capture and storage of atmospheric CO_2, improved water quality, reduced erosion, improved soil health	• Increased risks of vector-borne or water-borne diseases, and novel diseases into new regions with susceptible human populations
• Potential shift of marine and terrestrial ecosystems to carbon sources instead of sinks	• Unintended effects and tradeoffs with human security and well-being, e.g., leading to decarbonization divide

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Impacts on human health and well-being

Global changes have already affected the foundations of human well-being through complex interactions with social, political, economic and ecological conditions, with impacts already documented on health, infrastructure, economic and political stability, and food security [4,9]. Ultimately, they impact "the social determinants for good health, such as livelihoods, equality, and access to health care and social support structures" [4,23]. Global changes may also threaten human security, destroy peoples' livelihoods and habitat, or aggravate food insecurity [24,25]. The intensification of extreme weather events associated with climate change, from Australian bushfires [26] to the flash flood in Germany's Ahr valley [27], are drastic signs of severe damage to local ecosystems and human well-being. Climate change likely also reduces the "eco-physical buffering" [28] against such impacts. Rural and economically limited communities, migrants, ethnic minorities, and women are more exposed and vulnerable than wealthier and urban segments of society [29]. Several MOPGA projects examined how "climate-sensitive health risks" [23] unfold in multiple ways, through both changes in disease risk and through weather events, intensified by climate change, impacting the quality of air, food or water.

Solutions to the challenges of global change

While the main aim for organizations like the IPCC, IPBES, UNEP or European Environment Agency (EEA) was to produce assessments of environmental problems and their drivers, the scientific community is ultimately searching for feasible solutions to the challenges of global change. Much effort to counter rising temperature has focused on developing technologies that contribute to reducing emissions [30,31]. However, the ultimate efficacy and multifunctionality of technological approaches carries many uncertainties. While technological development is arguably an important part of the solution, many efforts have shifted to focus on substantial transformations of economies and societies, and understanding how such changes can be brought about [4,5,32]. The MOPGA program supported diverse efforts to increase and co-produce knowledge, inform decision-making, and develop both technological and nature-based solutions to accelerate the transformations that can address sustainability challenges (Table 3).

Technology development

The IPCC Sixth Assessment Report developed a new set of future scenarios of global development, called "shared socioeconomic pathways", that explores how different combinations of population growth, access to education, urbanization, economic growth, resources availability, technology developments and drivers of demand impinge on the impacts and mitigation of future climate change [33]. The panel concluded that only 30% of these potential socio-economic pathways were able to limit warming to 2°C. Those pathways require substantial reductions in emissions from all sectors and a major shift in energy investments away from fossil fuels and towards low-carbon technologies [4]. Energy sectors are

Table 3. Topics covered in MOPGA projects focused on solutions to the challenges of global change (for key findings and references see S3 Text; project numbers in S1 Table).

Technology development [Projects 8, 9, 10, 12, 19, 23, 24, 25, 26, 37, 40, 46, 53]	Adaptation and mitigation strategies [Projects 23, 26, 31, 32, 38, 42, 47]
• Improvements in efficiency of photovoltaic and photocatalytic conversion	• Socio-technical approaches to sustainability transitions, including system destabilisation, phase-out pathways, deploying strategies for low fossil carbon use
• Energy storage technologies, such as artificial photosynthesis and multicomponent materials	• Importance of "human-nature connectedness" and nature-based solutions, in particular in vulnerable regions (e.g., high altitude)
• Material and system development, including nanoengineering of battery and solar energy materials, photocatalytic systems, and modeling of fast biomass transformation	• Aspects of the food system affected by global change including food insecurity, greenhouse gas emissions from agriculture, farming techniques and agrobiodiversity
	• Design and evaluation of large-scale deployment strategies towards low fossil carbon use in France

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a main focus area of this transformation, but alternative energy sources from solar, wind, hydro, geothermal, and biofuel technologies require additional development and innovation to meet the demand [34]. Biofuels have been heralded as a promising alternative to intermittent resources such as wind and solar energy, but overreliance on bioenergies risks ”large-scale transformation of the land surface” [35] with resulting negative impacts on food security and biodiversity [4,5]. Besides decarbonization, enhancement of reliability, and diversification of the energy sources [36,37], the advancement of technologies to lower energy consumption, such as more efficient computing capabilities, are an important cornerstone for technology development in the context of global change. The MOPGA program supported innovation across these diverse technologies.

Adaptation and mitigation strategies

Besides technological advancements, it is crucial to understand and model other potential emission reduction pathways as well as adaptation options. Several MOPGA researchers criticized the so-called “techno-optimism” for overemphasizing technological fixes while overlooking the need for societal change [38]. MOPGA projects emphasized the importance of pluralizing the formulation and evaluation of sustainability transitions pathways [39], which can vary in feasibility [40], expense, rapidity [41], justice or ability to empower [42]. Such considerations are essential to ensure that responses are effective and economically viable. In addition, transformational societal changes are needed for climate stability, requiring a shift away from market-centered values toward greater recognition of nature’s benefits. Some MOPGA work has shown limited progress towards the 2030 Global Conservation Targets [43] but also that the implementation costs of nature-based solutions are considerably lower than the economic value of the ecosystem services they provide [44].

Major outcomes and future directions

The findings of the MOPGA program span an array of disciplines reflecting the complexity of global environmental problems and prospects for their resolution. Similar to the structure of the three working groups of the IPCC, researchers addressed the physical processes of global change on various scales, the natural and coupled human impacts of global change and a variety of technological, social and policy oriented mitigation and adaptation strategies. The program was successful in terms of producing 946 products (Table A in S4 Text). Based on products with a doi, we performed a scientometric analysis of the 752 MOPGA publications that were searchable on Web of Science (Methodological note in the supporting information). The resulting network map of co-cited journals (Fig 2) demonstrates that the citation landscape of MOPGA products is multidisciplinary in nature, reflecting the variety of scientific fields (disciplinary and interdisciplinary) within which the funded projects were inscribed and echoing the grouping of topics covered in MOPGA projects (Tables 1, 2, 3). The 11 distinct computed clusters all share an explicit link to climate and sustainability, and can be analytically aggregated into three macro-areas: *Geological & Biological Sciences*, *Global Climate Systems* and *Energy & Technology*. This analysis emphasizes how MOPGA provided a propitious opportunity for effective interactions across these diverse disciplines. We argue that building on this type of momentum will be a critical component in overcoming disciplinary boundaries. Some of the most important lessons came from these cross-disciplinary interactions.

We follow with a number of cross-cutting observations about how the MOPGA program was designed, its impact in terms of scientific production and fostering novel research practices, and what lessons it holds for the future of international science funding in troubled times.

Excellence and impact. With 946 products including over 885 scientific products with a digital object identifier (doi), and frequent communications at international scientific conferences, the scientific output of MOPGA is impactful in terms of volume, as well as in terms of dissemination (S4 Text, Part 2). The excellence and quantity of the MOPGA scientific output can partly be attributed to the selection of projects and laureates. The review process was well organized with two stages in both France and Germany : 1) pre-applications leading to invitations to submit full proposals (122 preselected scientists out of 340 in France, 62 preselected out of 287 in Germany) 2) external review of full proposals by

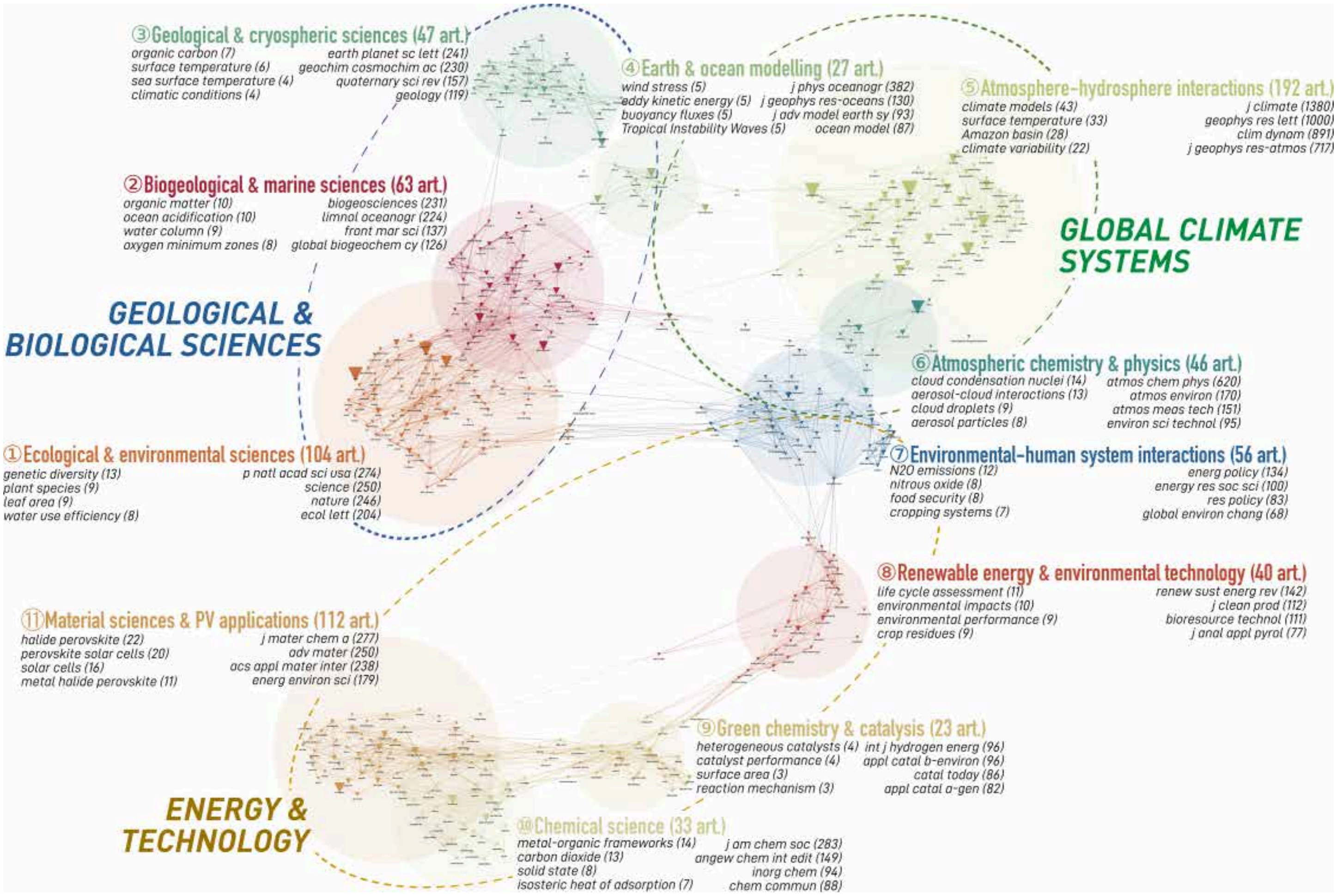

Fig 2. **The clustering of the network of co-cited journals, powered by the CorText Manager online platform [45].** The initial corpus is made of the top 5% cited journals (460) in 752 MOPGA publications that were searchable on Web of Science (Table A in S4 Text). The clustering obtained with a standard community detection algorithm reveals 11 clusters of most salient and distinctive associations of cited-journals across the program. To elicit the analysis of the map, some information has been added aside from each computed cluster: the title of the cluster with the total number of documents within it, the top 4 keywords and the top 4 cited journals (S4 Text). The relative positioning of these clusters reflects their internal constitution and their external relationships, depicting an epistemic landscape of cited journals, which are all indications of citation practices attributable to disciplinary or interdisciplinary configurations. At the macro level, we interpret connectivity between clusters as indicative of three macro-areas of scientific knowledge production: 1) under the remit of *Geological & Biological Sciences*, three central clusters concern Ecological, Environmental, Biological, Marine, Geological and Cryospheric sciences (clusters 1-3, top-left); 2) under the remit of *Global Climate Systems*, two central clusters concern Atmosphere-hydrosphere interactions and Atmospheric chemistry and physics (clusters 5-6, top-right); 3) under the remit of *Energy & Technology*, four central clusters concern renewable energy, environmental technology, green chemistry, catalysis, chemical science, material sciences and PV applications (cluster 8-11, bottom). Lastly, two clusters have an intermediary position, bridging between our three macro-epistemic areas: cluster 4 on Earth & ocean modelling that establishes a "bridge" between the macro-areas *Geological & Biological Sciences* and *Global Climate Systems* and cluster 7 on environmental-human system interactions which supports many edges between cited-journals that link the 3 macro-epistemic areas, showing the interdisciplinary nature of this cluster where some journals focused on social sciences and humanities mostly appear.

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experts from more than 10 countries and an independent international selection committee in both host countries. As a result, the MOPGA program funded 40 projects in France (12%) and 13 (5%) projects in Germany which is as selective as the overall prestigious ERC program from the European Commission (14%). Beyond the quantity and quality of scientific output of the MOPGA projects, it is difficult to know what the long-term impact of MOPGA will be on scientific fields, decision-making, practice, or society - given potentially long lead times in scientific impact and difficulties related to attribution. Nonetheless, currently available metrics (Table A in S4 Text) show that the 885 MOPGA products with a doi, considered in the analysis, are highly cited in scientific papers (23460 citations since 2018) and in policy documents (1593 citations since 2018), which suggests that authors and their research are highly visible and relevant in these domains. Future research could more effectively evaluate the impact of publications coming out of MOPGA and similar funding programs to assess whether and how they contributed to opening up new research fronts and what influence they have on societal debate and policymaking. More detailed societal impact analysis requires, inter alia, accounting for the lead times between the publication of research and its translation to non-scientific domains, and combining quantitative metrics with qualitative data (e.g. derived from interviews and field-level analyses) in order to achieve fine-grained insights about the conditions conducive to effective science-policy and science-society interfaces.

Perhaps the most critical component of the excellence of the program stems from the fact that the projects and research ideas came from the laureates and were reviewed and vetted by peer scientists. There was no political interference or agenda beyond the initial political willingness of President Macron and Chancellor Merkel to counter loss of scientific support stemming from the first Trump administration. The French ANR and German DAAD did not intervene with executing the grant, letting researchers change the specifics as warranted because the *French and German governments trusted scientists*. This contrasted with the political rhetoric of the first Trump administration, which signaled reduced federal support for certain areas of science, notably climate research. Under Trump, the U.S. science agencies such as the National Science Foundation and National Institutes of Health continued to operate with substantial autonomy and maintained their longstanding trust in the scientific community. But the federal political rhetoric created uncertainty about future support for specific research areas, especially climate-related work, furthered by recent funding and job cuts.

Another unique component of the excellence of MOPGA was the support for early career researchers - whether as grants to junior scientists or recruited on grants to senior scientists. This support ensured that the scientific pipeline was kept alive. Doctoral researchers particularly are financially vulnerable and face significant pressure in an academic labor market following the 'publish or perish model'. Such researchers will find that programs like MOPGA are an attractive opportunity. Support for PhD students can have important impact particularly in the social sciences considering talented PhD students may be more mobile thanks to the comparably modest physical infrastructure requirements required for top level research. We need such programs now more than ever, especially as the U.S. government has terminated probationary employees - many of whom are early career researchers trained in the latest methods and hopeful to lead future scientific endeavors if provided the opportunity. At the same time, these probationary periods also affect senior people taking on new leadership roles. The MOPGA program supported roughly half senior and half junior researchers.

Variety and relatedness of research. MOPGA was an open call within a very broadly defined research domain, and an explicit attention to multidisciplinarity. As expected, the results of the mapping exercise (Fig 2) show the spread of the resulting variety - i.e. through measures of the spread and proximity of the bodies of knowledge that the various research outputs refer to. The resulting spread of 11 distinct research clusters is indicative of the disciplinary and topical variety of the MOPGA epistemic universe. Further, we also see that 1) social science is largely underrepresented, and 2) interdisciplinary research connections remain selective, and to some extent within predictable patterns, such as via policy questions, or at the recognized interfaces of geophysical cycles. We turn to these two points next.

Less input from social sciences. It is well known, and regularly argued, that addressing global environmental challenges is not merely a technical issue, but one that largely rests on the political, organizational, and imaginative capacities of human societies to transform themselves to fundamentally alter current harmful patterns of human development. Consequently, there have been numerous calls for more social sciences [46,47], along with a pluralization of scientific and normative perspectives bearing on environmental sustainability problems [48]. It is essential that scientific funding more centrally reflects the political and social dimensions of environmental problems and the critical contributions of the social sciences to more effective, fair, just, and legitimate solutions to such problems. MOPGA reflects the current difficulty of social sciences to weigh in on scientific arenas. Of the 53 funded projects, three projects exclusively targeted human and social systems or human health and well-being. It is noteworthy that seven of the MOPGA projects primarily grounded in the biological and physical sciences have over time nurtured an interest in related social science problems and developed strategies to contribute to social sciences and knowledge transfer [49]. Thus, in total, ten of the 53 MOPGA projects addressed the effects of global change on social systems or human health.

For example, a MOPGA project focused on impacts of climate change on wild species expanded to explore the drivers of human-nature connectedness (HNC). These studies found that experience with nature (from city parks to wild expanses) increased people's empathy for nature, increased environmental activism and improved individual health [50]. Further, a cross-country study found that a developing country with high biodiversity (Colombia) had stronger HNC than the French. In both countries, children had the highest HNC, with a near loss of HNC in French teenagers, suggesting HNC is naturally high at birth, and lost to varying degrees through cultural processes [51].

Interdisciplinarity. It has also become well established that more interaction between disciplinary perspectives is essential to the emergence of critical new research [52]. This is particularly the case for research on global environmental change topics, given the mutual influence of bio-geo-physical dynamics and socio-eco-political dynamics. Further, interdisciplinary research practice is particularly challenging and time consuming - owing to the importance of bridging ontological and epistemological divides, generating trust across research teams, and learning [53].

The MOPGA program was not explicitly oriented towards interdisciplinary research, but several contributions in this direction are noteworthy. At the collective level of the MOPGA project cohort, laureates self-organized to convene cross-disciplinary dialogues and seminars involving scientific approaches and results across disciplines. Although MOPGA gained ground in substantive ways, the group faced two major shortcomings: first, interdisciplinarity was not a foundational objective of the program. We found that it is difficult to build successful interdisciplinary research strictly through interdisciplinary conferences or funding initiatives. We encourage expansion of programs (such as the Belmont Forum and Future Earth) designed for direct co-integration of interdisciplinary teams as an effective way to support shared problem framing, and mutual understanding of differences and complementarities. Immediate benefits to this approach are evidenced in global assessment processes, that have increasingly moved towards multi-disciplinary author teams. For example, in the last IPCC cycle (AR6), authors from disparate fields (e.g. atmospheric science, ecology, agriculture, and economics) worked together to develop Cross-Working Group Boxes (CWGB). Though challenging to find common ground, conclusions of CWGB were more relevant, accessible, and actionable than they would have been if addressed only within a single Working Group. Within MOPGA, laureates faced similar challenges to achieve understanding of the goals, approaches, and languages used by other disciplines distant from their own. Strikingly, early development of an interdisciplinary cohort-community led to cross-talk continuing to take place during the COVID-19 pandemic, in spite of severely limited in-person exchanges and meetings.

A second major challenge to developing interdisciplinarity was the length of the program. As the laureates' research began to truly benefit from connections between heterogeneous forms of knowledge and establish possibilities for interdisciplinary interaction beyond the design of their particular project (i.e. across projects), the program and funding ended. We also know that interdisciplinarity is a slow process that needs to be nurtured. It helps to design it into programs from the start, but it also needs continuity.

Ensuring continuity. One of the objectives of the MOPGA program was to attract excellent scholars from the USA to relocate to Europe. All laureates but one were hired in permanent academic positions during the course of the program, even though the full program was short-lived (there is a current French MOPGA program for one-year Post-doctoral Fellows) and was not tied to tenure-track programs. Several new full-scale funding schemes and institutional strategies may be even more likely to attract American scientists to Europe, given that all of science is now being undermined by the second Trump administration.

MOPGA was able to develop a strong sense of community within a relatively small group of 53 laureates and their newly formed research groups with a program that lasted up to five years. The program brought together participants both physically and virtually to exchange ideas, results and argue interpretations. This was particularly true at the three full program meetings: the inaugural meeting in Paris in 2018, the mid-term conference meeting in Strasbourg in 2021 and the final meeting in Berlin in 2022. At these meetings each laureate presented their work, but importantly representatives of the different disciplines made up the scientific board who put together the agenda. Moreover, the format was such that all laureates were exposed to the work of all other laureates since there were no "concurrent" sessions. Instead, each laureate created a short talk for a broad scientific audience that was practiced and discussed during interactive virtual meetings prior to the conferences. Soon after the mid-conference meeting, the laureates established a weekly online seminar where each laureate could give a full length talk about their research to the other laureates to get feedback and facilitate cross-talk (https://www.youtube.com/@makeourplanetgreatagain5251/playlists). The program also provided opportunities for young researchers to create and coordinate new research teams and projects. Follow-up MOPGA projects (e.g. One Health, 2022-2023) have already been leveraged to support additional interdisciplinary efforts.

Despite many challenges, the interdisciplinary exchange among laureates influenced within-discipline research questions, interpretations of data and general conclusions. The success achieved in the MOPGA framework highlighted that increasing interdisciplinary cross-talk and networking is as important to moving our understanding forward as is generating specific disciplinary projects. At the closing meeting in Berlin, MOPGA laureates articulated that future programs should support research projects that embrace ecological, geophysical, social and technological solutions from the start. The need for such bold, independent scientific initiatives is now greater than ever.

Supporting information

S1 Text. Understanding Processes of Global Change.
(DOCX)

S2 Text. Impacts of Global Change.
(DOCX)

S3 Text. Solutions to the challenges of global change.
(DOCX)

S4 Text. Methodological note.
(DOCX)

S1 Table. The 17 major research categories treated in the individual MOPGA projects.
(XLSX)

S2 Table. Research products created by the MOPGA laureates.
(XLSX)

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