



Food systems science for peace and security: Is research for development key for achieving systematic change?

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A B S T R A C T

This paper uses CGIAR research as an example to demonstrate the potential of food systems science to contribute to conflict prevention and peacebuilding. Conflict often arises through a complex process whose triggers and consequences are closely interconnected in feedback loops and linked to climate variability, environmental degradation and food insecurity. Conflicts are often approached from a symptomatic rather than a holistic perspective. We (i) review the literature on climate security to identify conflict pathways and related drivers. This serves as the basis for mapping CGIAR and partner research related to climate security through a portfolio review (ii) and facilitated multidisciplinary expert panel discussions (iii). We then define cross-cutting priorities for the future direction of climate security debates, policies and programmes and link them to the new One CGIAR strategy. Conflicts pathways related to food systems, migration and weak governance were among the most studied conflict drivers found in the literature. The same drivers are also frequently studied by CGIAR and addressed by conveying knowledge and tools on disaster- risk reduction, climate change adaptation and livelihood resilience, among others. Four cross-cutting priorities for peacebuilding emerged from the panel discussions: (1) integrating food systems science into policy conversations; (2) bridging the gap between food systems science and security through data and new technologies; (3) financing to build sustainable livelihoods for conflict-affected populations; and (4) multidisciplinary partnerships. CGIAR, its many partners and partner research and development initiatives, are well positioned to demonstrate the potential of food systems science to contribute to peacebuilding.

Introduction

Climate variability, natural disasters, and extreme weather events such as droughts, floods and wildfires are having increasingly serious impacts on natural and human systems through the alteration of ecosystems, perturbation of food production and water supply, and the destruction of infrastructure [1]. If widespread and effective mitigation and adaptation strategies are not implemented, far-reaching negative consequences for economic growth, poverty, food security, and many other aspects of human and natural systems are expected in many regions worldwide. Marginalized and poor people suffer the consequences most and will continue to do so [1].

One of the many impacts of climate variability is its potential threat to human security [2] Especially since 2007, when political leaders began making statements on the negative effects of climate variability on human security, numerous research programs and special issues in academic journals as well as discussions on (social) media and in the blogosphere have emerged [3,4]. Climate security, focusing on the role of climate variability as a threat multiplier, has not only been dedicated a chapter in the most recent report by the Intergovernmental Panel on Climate Change [1], but is also incorporated into the security planning of many states that have published security strategies [1,5].

The global numbers of conflicts (state-based, non-state and one-sided violence) has increased substantially in the last ten years, from 82 in

2009 to 169 in 2020 [6]. Some contemporary conflicts have been linked to extreme weather events. While this link has been highly controversial in cases such as the Syrian civil war [7,8], it has gained recognition for its role in conflicts in some regions of Asia and Africa [9,10] and within countries such as Somalia, India and Indonesia, where rural incomes are an intermediating factor within the extreme weather – violent conflict pathway [11–13].

In recent years, the role of climate variability as a possible cause of violent conflict has been investigated extensively by the scientific and political communities [25]. However, there is little consensus on the subject: numerous studies support the climate-conflict nexus (e.g., [14]) while others question it (e.g., [15]). Subsequently, several high-quality reviews have been published on the topic [3,16–18]). Nevertheless, controversies about the pathways and importance of the climate-conflict nexus continue.

There are several reasons why there is no consensus on the role of climate in peace and security. First, studies use different measures and concepts for climate and conflict [19,20]. There is also considerable heterogeneity in both the spatiotemporal and social scales at which climate–conflict links are explored, which is crucial to how the issue is conceived and understood [16,20,21]. Moreover, there is the so-called “streetlight effect” in climate security research, whereby studies concentrate on regions more vulnerable to climate variability or conflict and hence, potentially overstating the relationship [22–24].

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Despite the lack of consensus on the topic, a recent study synthesizing structured judgments of the best experts in the field succeeded in establishing more robust conclusions on the climate–conflict relationship [25]: Climate variability has influenced the risk of violent conflict within countries in the past and is expected to do so in the future. In this, it is not climate variability itself that is increasing the risk of conflicts, but its interaction with a range of factors related to low socio-economic development and low state capability [25,26]. Furthermore, there is substantial evidence that climate-related conflict is more likely to emerge in regions that are vulnerable to climate variability and are characterized by high levels of poverty, political inequality, and dependence on renewable resources, especially agricultural production [9,26,27].

The impact pathways between climate and conflict remain unclear. However, one of the most plausible and acknowledged mechanisms is related to economic hardship through the effects of the agricultural sector and food prices [21,25,28]. Even though these complexities are difficult to demonstrate analytically, poverty and food insecurity are deeply ingrained in many agricultural systems, and magnified by other factors, interconnected with conflict [29–31]. The fact that, for instance, in 2017/18, all countries experiencing a protracted crisis or high risk of famine were simultaneously affected by violent conflicts reflects this interconnection [32].

The literature suggests three possible pathways linking climate to violent conflict [27,33]: (1) linear, causal linkages, for instance between increased temperatures and civil war (e.g., [34]); (2) indirect linkages through intermediate factors, for example through decreasing economic production and crop yields, rising food prices, and increasing migration flows (e.g., [35]); and (3) context-specific linkages between climate and conflict. This is based on the assumption that the climate directly or indirectly affects conflict intermediated by contextual factors, i.e., institutional, political and socio-economic factors (e.g., [9]). Systematic reviews point towards the latter to be the most comprehensive approach to understanding the climate–conflict nexus [25,28,36]. The relationship between adverse climate, agricultural and economic conditions and conflict, in the context of institutional, social, and political environments has been confirmed in several publications, from both country-specific and global studies [11,12,37].

Some years ago, researchers began calling for more concentration on studying the role of the agricultural sector in conflict development [3]. Virtually all seven compound climate–fragility risks identified in the G7 report, “A New Climate for Peace”, are directly or indirectly related to agricultural production [16,38]. The resilience of food systems, to contextualize agricultural production as part of a larger system, is therefore fundamental in understanding and tackling climate security risks. This view is shared even by some scholars who question the relationship between climate variability and conflict [16]. Agricultural research for development may therefore play an essential role not only in alleviating poverty and food insecurity but also in identifying ways of reducing the risk for potential conflicts [31,39].

Building on this conclusion, this paper aims at identifying the potential of food systems science to contribute to peacebuilding, using the example of CGIAR and partner research. CGIAR¹ is a global agricultural research network collaborating with national agricultural research systems, universities, development organizations, bilateral and donor governments, foundations and financial institutions. Established in 1971, it is dedicated to advancing research on food systems in the global south. Its research aims at promoting sustainable development of agriculture and agroecological systems to reduce rural poverty and food insecurity, improve health and nutrition, and ensure sustainable management of natural resources. CGIAR research focuses on areas that are dependent on agriculture (including fisheries and forestry), and whose rural populations are vulnerable to food insecurity, malnutrition, degradation of

natural resources, climate variability, and conflict. Fifteen independent research centers have been forming the core of CGIAR in the past, however to further strengthen its contributions to achieving the Sustainable Development (SDG) goals, CGIAR Centers and Alliances are being consolidated into a smaller number of partnership-driven operational units under the rubric of “One CGIAR” [41].

CGIAR and its many partners such as Wageningen University, center de coopération internationale en recherche, the Indian Council of Agricultural Research, the Food and Agriculture Organization, the World Food Programme, the European Union, United States Agency for International Development, the Deutsche Gesellschaft für Internationale Zusammenarbeit, the World Bank, and the Bill & Melinda Gates Foundation, among many others, can be considered as a global association of public and private organizations. Between 2017 and 2020, more than 3200 partners have worked with the CGIAR and more than 840 partnerships (i.e., a recognized relationship between CGIAR Research programs and platforms and other institutions external to CGIAR) have been formed [40]. Therefore, we use CGIAR and partner institutions as an example for agricultural and natural resource institutions working on water land and food systems.

Even though conflict research and emergency relief are not CGIAR’s mandate, its food systems research, by addressing key intermediary conflict drivers, directly or indirectly relates to climate and security. To explore this potential, in the next sections we first review existing literature on climate security to establish a conceptual overview of conflict drivers and pathways. This serves as a base for mapping CGIAR and partner research for development on agriculture and food systems in the context of climate security through a portfolio review. We then document the outcomes of multidisciplinary expert panel discussions involving discourse between different fields of research and practice. This enables us to define cross-cutting priorities for future directions in climate security debates, policies, and programming, and to link them with the One CGIAR strategy.

Materials and methods

Literature review (i)

A literature review was conducted to establish a conceptual overview of climate security research and to identify conflict drivers and pathways. The review focused on peer-reviewed journal articles published on the intersection between climate and conflict from the environmental, agricultural, and geopolitical sciences. Google Scholar and the literature search function from Mendeley Desktop were used for the search. A total of 197 papers on climate security were screened, of which 67 were used to build a database of drivers, conflicts, and where available, pathways. We mainly used studies analyzing and finding statistical associations between climate variability and conflict. Tables 1 and S1 Table provide a summary of key data on the methods we used, and conflict types, driver categories, and regions.

Portfolio review (ii)

The drivers of conflicts identified from the literature were used to orient the search and mapping of CGIAR research contributions for a portfolio review on climate security Fig. 1. A portfolio review is a type of research evaluation and assessment in terms of accountability, resource allocation, analysis, and advocacy of research projects, programs, or institutions [42]. The purpose of the present portfolio review was to analyze how CGIAR and partner research is contributing to the subject of climate security, how future research and collaboration could further strengthen CGIAR’s role in the field, and how CGIAR research results can be used by policymakers and practitioners for more informed decision making. Two CGIAR publication repositories were screened for relevant research contributions using the keyword combinations listed in Table 2. The Global Agricultural Research Data Innovation Acceleration

¹ The authors are affiliated to the CGIAR, and would like to assure that the paper is an outcome of an objective evaluation of what CGIAR represents

Table 1
Summary of some key data on used methods, conflict types, driver categories and regions.

Method	#	Conflict type	#	Driver category	#	Region	#
Statistical analysis	41	Violent conflict	74	Environmental	87	Africa	29
Systematic review	7	Land and natural resource conflict	5	Social	51	Global	24
Qualitative case study	6	(Inter)Communal conflict	4	Institutional/Political	26	Asia	9
Theoretical / conceptual	5			Agronomic	21	South America	4
Quantitative case study	4			Economic	17	Europe	1
Spatial risk analysis	2						
Integrated approach	2						

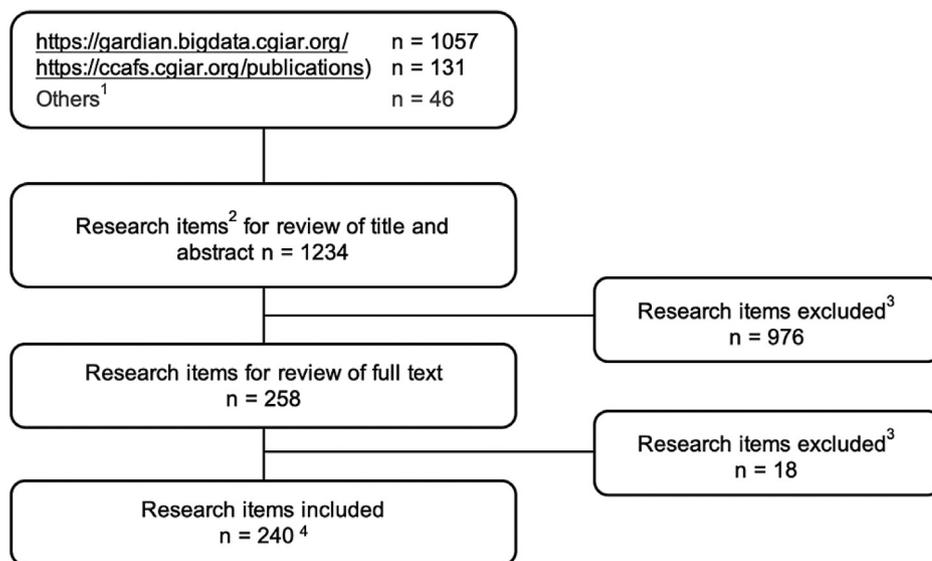


Fig. 1. Process of CGIAR portfolio review on climate security research. ¹ Others = Research items from <https://www.ifpri.org/topic/food-crises> and those shared by partners via email. ² Research items include journal articles, working and discussion papers, books, book chapters, manuals, guides, tools, policy and research briefs, conference papers, abstracts and proceedings, project reports, annual reports, scientific multimedia (data platforms, blogs, webpages), project descriptions, workshop reports, and theses. ³ Duplicates or research items irrelevant for the objective of the portfolio analysis were excluded. ⁴ The final number of research items contributing to climate security is not exhaustive, as only two out of the many CGIAR data repositories were used.

Table 2
Keywords and total search results.

Keyword	Search results ¹
Climate change and conflict	224
Climate change and migration	178
Climate services and country ²	113
Resources and conflict and country ²	102
Drought and conflict	87
Drought tolerance	77
Flood and conflict	35
Crop insurance	211
Forecasting and early warning systems	102
Others	59

¹ CGIAR centers were not necessarily leading every project. If one was involved in producing a research output, it was considered as a contribution.

² The search was tailored to conflict affected countries, e.g., Congo, Sudan, Somalia, Mali, South Sudan).

Network [43] facilitates the discovery of publications and datasets from the thirty-odd institutional publications and data repositories across all CGIAR centers to enable value addition and innovation via data reuse. It employs text-mining to enrich the associated metadata to enhance discovery. The CGIAR Program on Climate Change, Agriculture and Food Security (CCAFS) repository was the second database used [44]. It features a collection of all CCAFS related publications, projects and tools, searchable via multiple filters and limiters. Relevant research items were selected and data on drivers and conflicts analyzed along with other metadata from project partners and study locations were extracted. A research item was considered as relevant if it directly or indirectly addressed at least one of the conflict drivers identified from the literature review. A detailed protocol can be found in the supplementary material S1 Protocol.

Multidisciplinary panel discussions (iii)

To align discourses characterizing different disciplines and areas of expertise, and to define cross-cutting priorities for future directions in climate security debates and policies, we hosted multidisciplinary panel discussions via an eight-part webinar series with experts representing a variety of perspectives and respective institutions, including food systems science (n = 6); peace research (n = 4); political science (n = 2); climate science (n = 1); humanitarian relief organizations (n = 3); financial institutions (n = 5); governments (n = 7); European institutions (n = 2); and non-governmental organizations (n = 3). We assessed the expertise of participants through a review of potential speakers followed by a scoring against the topics of the webinar. The discussion topics included:

- 1 The role of climate and food systems science in conflict prevention and peacebuilding.
- 2 The role of data and disruptive technologies for climate security.
- 3 Sustainable finance for peace.
- 4 Climate security in the Sahel.
- 5 Climate security in Colombia.
- 6 Partnership agenda for climate security.
- 7 Charting the path to peace: who bears the burden of climate variability in Vietnam?
- 8 Charting the path to peace: who bears the burden of climate variability in Indonesia?

S3 Table gives further information on participating experts and their affiliations. R4D and CGIAR operate mainly in countries where peace and stability needs be strengthened or built rather than countries at war. We selected contrasting countries, Colombia for being a post conflict country, Indonesia for its environmental concerns (deforestation and depletion of natural resources) which links to climate and security alike and finally Vietnam for its existing inequality and tension which

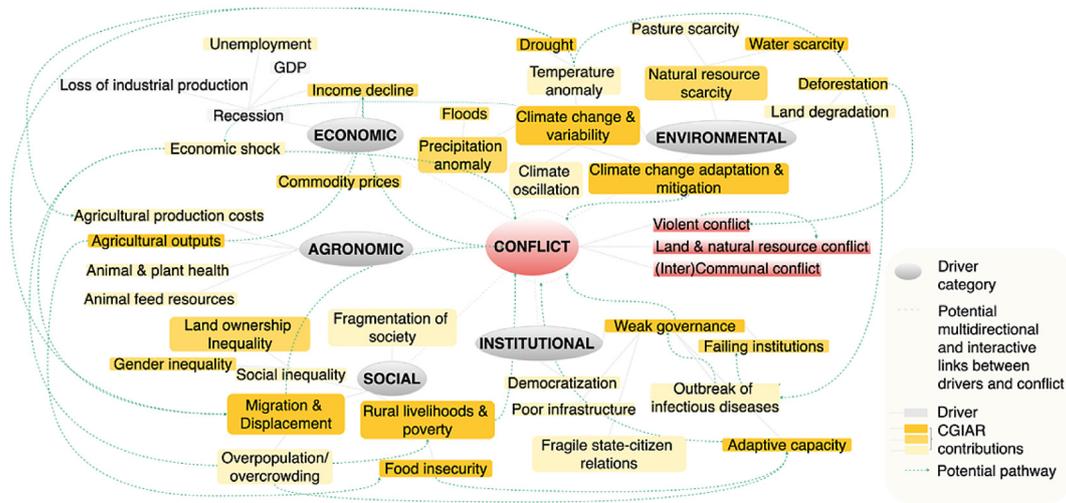


Fig. 2. Conceptual network of driver interactions in the context of the climate-conflict nexus. Orange boxes indicate CGIAR's work on the prospects for peace (the orange tone corresponds to the frequency of addressed drivers, Fig. 3a).

are difficult to measure and describe given the centralistic government structure and rules.

The panel discussions were transcribed and key messages extracted.

Results and discussion

The impact pathways of the climate-conflict nexus in the literature (i)

From the literature review of the 67 research papers, 37 conflict drivers were identified and classified into five overarching categories: ecological, economic, agricultural, social, and institutional S1 Table and S2 Table Fig. 2. is a conceptual representation of driver interactions in the context of the climate-conflict nexus, based on the literature. Agricultural outputs, e.g., livestock or crops produced for sale or consumption, rural livelihoods and poverty, food insecurity, migration and displacement, as well as weak governance were among the ten most studied conflict drivers interacting with climatic variables such as drought, water scarcity, precipitation or temperature anomalies, or climate variability in general. Conflict pathways including agricultural mechanisms link climate variability to economic hardship, and economic hardship to conflict [3]. These mechanisms are explained in detail in the following sections.

Rainfall anomalies and droughts translate not only into reduced agricultural production, food insecurity and rising food prices, but also loss of livelihoods and a decline in associated economic activities such as trade [12,45–48]. It has also been shown that the risk of social and political conflict was especially increased for politically marginal communities dependent on rainfed agriculture [9,49]. These studies largely focus on Africa.

In general, agriculture is the sector most affected by the impacts of climate change [3]. Abnormal rainfall and temperature are estimated to explain more than 30 percent of the yearly variation in global crop yields [50]. Erratic rainfall, temperature fluctuations, and unpredictable natural disasters such as droughts and floods often reduce agricultural productivity [51]. Even though agricultural communities have developed strategies to cope with these uncertainties, the consequences of adverse climatic conditions can be immense for rural livelihoods, poverty, and food security [3,52].

In explaining the link between undermined livelihoods and increased poverty and food insecurity on the one hand and conflict on the other, there are several competing theories. Some authors argue that reduced agricultural output and the consequent impacts on rural livelihoods and competition over natural resources cause grievances or criminal activ-

ities that motivate conflict behavior, potentially by decreasing the opportunity cost of rebellion [53–55]. Others suggest conflicts are offset via domestic or international migration [56,57]. Climate-induced domestic and international migration and its relation to conflict itself has been the subject of multiple studies. Different pathways are proposed for linking migration to conflict, for instance via natural resource competition in the receiving countries, or ethnic tensions between displaced and receiving communities [56]. Other studies conducted in India, Nigeria, Ethiopia, and Bangladesh, respectively, agree that migration may be influenced by weather anomalies and that it may contribute to conflicts, especially where rainfed agriculture persists [58,59].

There is strong consensus that the institutional and political environment determines whether climate-driven migration, agricultural and economic downturns, or other drivers lead to conflict [27,33]. Climate-induced food insecurity may result in conflict if a state's institutional capacities and political system, including the strength of the agricultural sector, are not capable of mitigating food shortages and insecurity [60]. Climate-induced migration may also result in conflict if the economic situation and adaptive capacity of the receiving region are weak [56,61]. Also, weak governance, non-democratic systems, and ethnically fractionalized and politically excluded minorities increase the risk of climate-related conflicts [13,49,62]. Therefore, environmental issues and climate-driven phenomena, including the pathways via agriculture, are a catalyst for conflict, while the extent to which both local and international institutions can intervene and mitigate the impacts is critical to whether a conflict escalates or not [28,63].

Disentangling the climate-conflict nexus is highly complex, both conceptually and analytically, especially given the importance of institutions and the state [29–31,64]. Taking into account the multitude of causal and feedback loops is crucial. However, research has often perceived the climate–conflict nexus as a unidirectional flow from climate to conflict [16,21,64]. For instance, high food prices or food insecurity increase the risk of violent conflicts, which in turn increase food prices or food insecurity [31,48]. Environmental change may increase fragility and conflicts, while governance failures may worsen environmental damage [65]. Climate variability can be seen as a threat multiplier for conflict, but conflict can also exacerbate climate variability by negatively affecting the environment (e.g., via deforestation) and conflict in itself can be a strong driver fueling existing or new conflicts [25,66]. Climate change adaptation strategies aiming to decrease the impacts of climate change (and ultimately mitigate climate-induced conflicts) may not only have negative impacts on food security or labor markets but may also be a catalyst for conflicts [16,67,68]. Finally, and

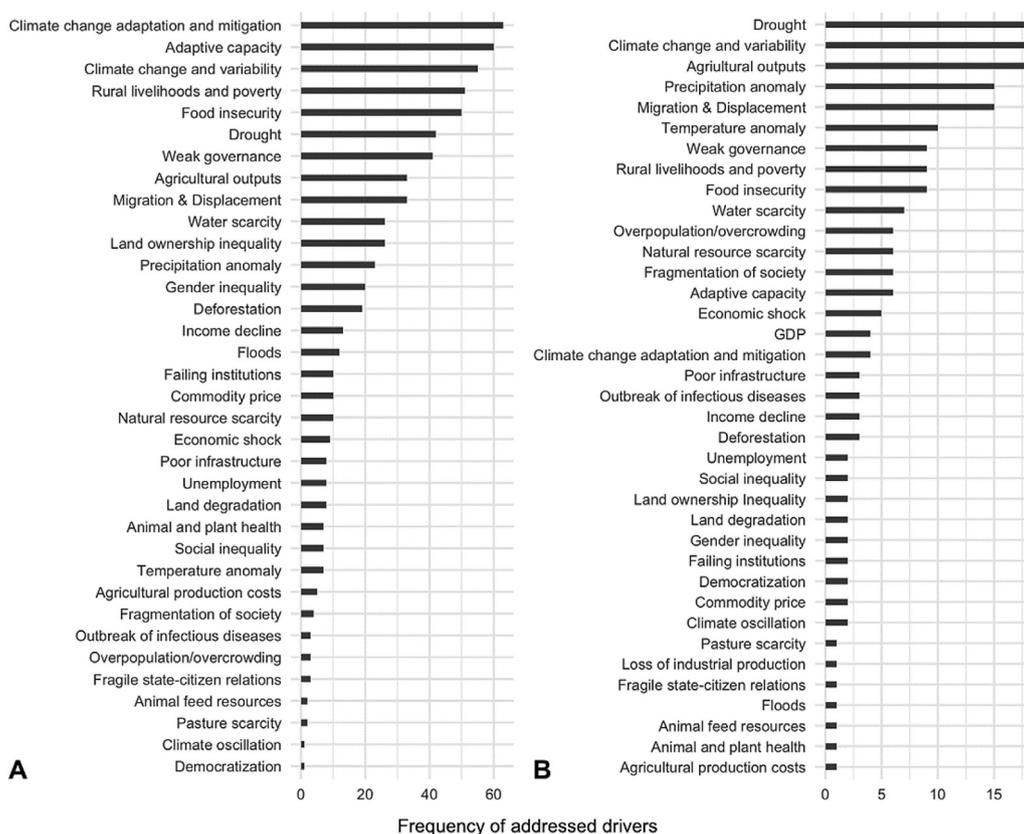


Fig. 3. Addressed drivers of conflict found in portfolio (A) and literature review (B).

controversially, climate change and variability can even be seen as an “opportunity” for peacebuilding, for instance when climate smart agricultural techniques and better natural resource management as adaptations to climate change are integrated into the peacebuilding process [16,69].

CGIAR portfolio review (ii)

The portfolio review gives insights into how CGIAR and partner research is contributing to the subject of climate security, how future research and collaboration could further strengthen CGIAR’s role in the field, and how better understanding of CGIAR research could be promoted among policymakers and practitioners. The portfolio review shows that the most studied conflict drivers by CGIAR largely match those found in the literature review, hence significantly contributing to peace and security (Fig. 2). Eight out of the top ten drivers found in the literature review are also those most frequently addressed by CGIAR researchers. These are climate-related topics (climate variability, drought, water scarcity, climate change adaptation, and mitigation), agricultural output, rural livelihoods and poverty, food insecurity, migration and displacement, adaptive capacity and weak governance (Fig. 3). Concerning project locations, countries in the Sahel and Horn of Africa, as well as South Asia were the most frequently studied, with Mali, Ethiopia, and Kenya being the top three locations where most research on climate security was found (Fig. 4). The following sections offer examples of CGIAR contributions around these conflict drivers.

Climate information and services, i.e., the timely provision of important climate data to decision-makers [70], is an area CGIAR has focused on intensively during the last decade. One of the many examples is CCAFS’s Climate Information Project in Senegal, which, in collaboration with the Senegalese National Meteorological Agency, aims at improving the delivery of climate information such as seasonal rainfall forecasts and agricultural advice to Senegalese farmers on a large scale

[71]. Farmers use this information to plan sowing dates or to select crop varieties, reducing potential crop losses as a consequence of unexpected weather events. Another example is index-based flood insurance (IBFI), a climate-smart safety net for farmers in flood-prone-areas developed by the International Water Management Institute (IWMI) under CGIAR’s research programs on Water, Land, and Ecosystems (WLE) and CCAFS [72]. Using satellite imagery and rainfall data, the IBFI system integrates flood thresholds with insurance products for people living in flood-prone areas. It was conceptualized in India and Bangladesh, where almost 2000 farmers were insured between 2017 and 2019.

By supporting climate change adaptation, disaster risk reduction and strengthening livelihood resilience, these initiatives reduce incentives for violent conflict. They are based on recognized principles of environmental peacebuilding [24,73]. Aiming at mitigating conflicts by integrating natural resource management and climate change adaptation into the peacebuilding process, environmental peacebuilding is an example of how climate change and variability can also create opportunities for peacebuilding. An ongoing project led by CGIAR’s International Center for Tropical Agriculture (CIAT), for instance, targets forest conservation, the reduction of greenhouse gas emissions, and restoring degraded landscapes while improving livelihoods and promoting peacebuilding in conflict-affected areas of Colombia [74]. The same working group has also studied the co-benefits of climate action, with a focus on forest carbon-storage as a strategy for peacebuilding. In light of the Colombian peace agreement and worries about its implications for forests, relationships between forest cover, deforestation, and armed conflict were investigated, as well as motivations of farmers to conserve forests [75,76].

To provide potential sustainable food security strategies for rural livelihoods, the International Food Policy Research Institute (IFPRI), in collaboration with the European Commission, has developed the Food Security Portal [77]. It contains open-access information on food secu-

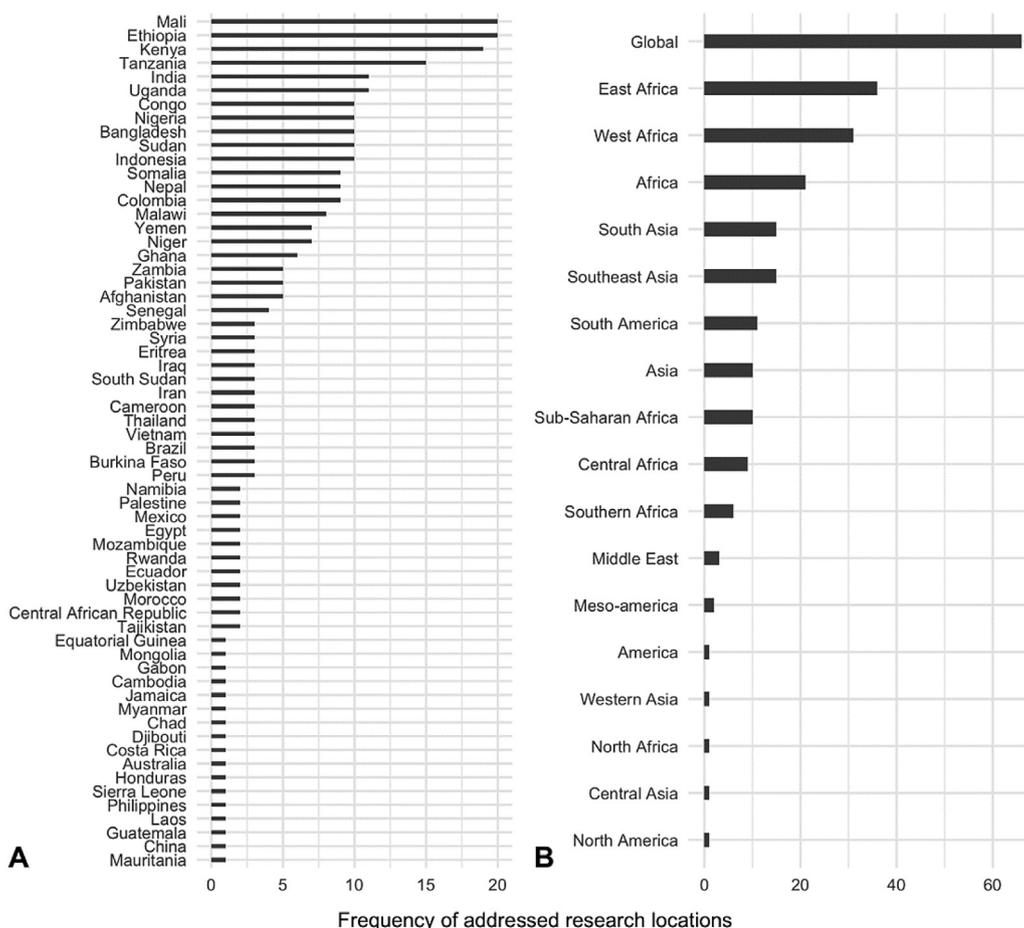


Fig. 4. Addressed countries (A) and regions (B) in portfolio review.

riety issues, allowing policymakers to respond around the globe in time by providing country-level data for early warning and monitoring systems and on commodity prices, as well as tools for policy analysis. They are also part of the Food Security Information Network [78], a technical platform for exchanging expertise on food security and nutrition analysis. FSIN produces an annual Global Report on Food Crises. IFPRI has also done extensive work on how to build resilience to conflict via the role of food security. For example, IFPRI has developed a framework in which food-security-related policies and programs in conflict-prone areas are given a high priority, and used it to analyze conflict situations in Somalia, Sudan, Egypt, and Yemen [79].

Furthermore, IFPRI is also providing a thematic collection of research publications, datasets, and tools on the conflict-food insecurity-migration nexus and how conflict and food insecurity drive migration [80]. Its 2020 Global Food Policy Report, which analyses the association between conflict and food insecurity, suggests policies to integrate the topic of conflict refugees into food systems [81]. This is being implemented in an IWMI and World Agroforestry (ICRAF) project which is piloting and scaling up adaptable and gender-responsive “resource recovery and reuse” solutions for increased food and energy security and sustainable socio-ecological systems in refugee settlements and host communities in Ethiopia, Kenya and Uganda [82].

The effectiveness of these interventions will depend on the enabling environment. Therefore, CGIAR work also aims at strengthening institutions and governance to increase adaptive capacities. For instance, through CCAFS’s Climate-Smart Agriculture Plan (CSA-Plan), a climate-smart agriculture planning, programming and implementation guide has been developed in collaboration with CIAT and ICRAF. Capacity building, policy engagement, and understanding institutional arrangements are cross-cutting elements of the plan [83]. The guide highlights the im-

portance of building local institutional frameworks, strengthening the role of meso-level institutions, and working to enhance national institutional capacity to implement policy decisions. Another example of initiatives aiming at understanding and strengthening socio-economic and institutional environments is the Global Comparative Study on Forest Tenure Reform, led by the Center for International Forestry Research (CIFOR) under the CGIAR Research Programs on Policies, Institutions, and Markets (PIM) and on Forest, Trees, and Agroforestry (FTA). Through an institutional analysis lens, this comprehensive research program explores policies, legal frameworks, institutions, and practices around forest tenure reforms, to improve the knowledge, understanding, and skills of policymakers, practitioners, and forest-dependent communities for the design and implementation of forest tenure reform. With case studies from conflict-affected regions in Uganda, Indonesia, Nepal, and Peru, the project outcomes also aim at improving conflict management over land resources [84].

It is undisputed that climate change and variability are impacting our food systems, and that food systems play an integral part in conflict. Therefore, interventions addressing disaster-risk reduction, climate change adaptation and livelihood resilience present a promising opportunity to prevent many conflicts [36]. CGIAR’s diverse research portfolio offers knowledge and tools to design these interventions, which include climate-smart agriculture tools, climate information and services, early warning systems for disaster-risk reduction, insurance schemes and social safety, technical support for national, regional and local agricultural services as well as farmers, and the development of drought, flood, pest or disease resistant crops, among others.

In addition to increasing resilience, these interventions may also contribute to political stability, for instance by enhancing trust in institutions or improving fragile state-citizen relations [36]. However, strong

Table 3
Summary of main messages from expert panel discussions.

Discussion topic	Key points
The Role of Climate and Food Systems Science in Conflict Prevention and Building Peace	There will be direct impacts of climate variability on the food security of many vulnerable communities around the globe, which in turn may contribute to conflict via complex pathways. Integrating food security and food systems science into research and policy conversation is key for conflict prevention and peacebuilding.
The Role of Data and Disruptive Technologies for Climate Security	Data and new technologies are key in bridging the gap between food system science and security. There is a need to reduce barriers in data access and management, and to create a platform for deep integrations where humanitarian and development communities can work together.
Sustainable Finance for Peace	Private and public finance mechanisms are needed to establish sustainable livelihoods for populations within regions prone to or recovering from conflict.
Climate Security in the Sahel	To address the multi-dimensional nature of the factors affecting people's security and dignity in the Sahel, working not only with the military but also with a human security type of framework is necessary. Furthermore, longer-term perspectives, such as resilience tools from R&D, instead of simply reactive responses such as military actions have to be adopted.
Climate Security in Colombia	Violence, inequality, faulty governance, and climate variability are aspects of the conflict situation in Colombia. The willingness, consciousness, capability, and creativity of Colombians as well as effective governance systems are needed to develop mechanisms to overcome all of these challenges. Science plays a role in this, when being embedded in policymaking, politics, and institutional strengthening.
A Partnership Agenda for Climate Security	Interventions should be designed through partnerships, integrating issues of basic development, food security, and community stability, and focus on context-specific situations. As the climate-security-nexus is a highly multi-disciplinary topic, there is a need to build on and strengthen existing networks.
Charting the Path to Peace: Who Bears the Burden of Climate Variability in Vietnam?	To ensure a sustainable economic development in Vietnam, local governance and participatory planning mechanisms should be strengthened, differences across cultures between majority and minority groups should be appreciated, and climate impacts should be mainstreamed into decision-making processes, focusing on youth, and a more equal distribution of wealth and opportunities.
Charting the Path to Peace: Who Bears the Burden of Climate Variability in Indonesia?	To mitigate the impact of climate variability on the inequality of opportunities for the poorest and most marginalized people in Indonesia, evidence on who bears the biggest burden of climate impacts should be strengthened and integrated into social protection programs, investments and policies should be mainstreamed, and the recognition of people's rights over natural capital, improving land governance and investments in renewable energy should be enforced.

governance and an understanding of the socio-economic context are preconditions for the successful and sustainable implementation of resilience interventions [85]. Therefore, regions with ineffective institutions, weak economies, and political marginalization should be targeted [36]. According to the Fragile State Index, the most fragile areas include parts of Central and South-East Asia as well as South America, the Middle East and especially the Sahel and Horn of Africa, for which most of the scientific evidence on the climate-conflict relationship exists [86], and which overlaps with locations where CGIAR research is conducted.

Cross-cutting themes emerging from multidisciplinary panel discussions (iii)

The webinars were conceived to align different narratives, and to define cross-cutting priorities for future directions in climate security debates, policies, and programming Table 3. summarizes the key points emerging from the discussions. In the following, four cross-cutting priorities that emerged from the webinars are discussed.

Food systems research for climate security

In line with the literature and portfolio review, the expert discussions confirmed the roles of climate and food insecurity of vulnerable communities in generating conflict, and hence the significance of integrating food systems science into peace and security debates, policies and programming. It was acknowledged that increasing hunger worldwide is driven primarily by climate change and violent conflicts; and food is foundational for peace. Policies, programming and finance for strengthening food systems thus need to include climate action and conflict mitigation. CGIAR's new strategy to 2030, "Transforming food, land, and water systems in a climate crisis" will be critical to delivering the science needed to understand how climate exacerbates drivers of conflicts and exerts pressure on peace and security. CGIAR's new strategy is broader than its previous strategies and specifically includes planned contributions to SDG 16 on peace, justice and strong institutions, while the main impact area remains on SDG 2, ending hunger [41].

Importance of data and new technologies for climate security

To bridge the gap between food system science and security, the importance of data and new technologies for climate security was em-

phasized. Science, via the use of data, remote sensing techniques, and innovative analytical and statistical approaches, can speed up the learning process and give a real-time vision on agricultural processes or food security trends, enabling anticipation and prevention of disasters and thus contributing to mitigation of potential conflicts. CGIAR research has traditionally been strong on data and technologies through its Platform for Big Data in Agriculture and extensive work on climate information services, early warning and insurance [87]. This work will continue to be central to CGIAR's new strategy under the action area on systems transformation of food systems driving sustainable land and water use, livelihoods, and healthy diets.

Sustainable finance for climate security

Five years after the adoption of the SDGs, funding resources are falling remarkably short – with an enormous gap of USD 2.5 trillion annually. All too often, climate and security policies are not aligned, and humanitarian, development and peace objectives are competing for primacy and resources. Harmonized finance along the humanitarian-development nexus is needed to align objectives, incentives and use of resources and ensure that investments mutually reinforce each other. CGIAR has demonstrated already, in the case of cacao in Colombia, how mitigation, resilience and peace building objectives can be aligned [88]. In the new CGIAR strategy, sustainable finance is a key component, acknowledging the enormous gaps in public resources. Early examples show how research for development can catalyze private investments, bundled with public funding for de-risking in areas where otherwise no resources would be available [89].

Partnerships and multidisciplinary collaboration for climate security

A cross-cutting theme in all the panel discussions was the importance of multidisciplinary collaboration to guide climate security debates, policies, and programming. The importance of collaborating with different stakeholders, i.e., from regional to national to community levels as well as the United Nations and, for example, the European Union, was highlighted, as a means of providing evidence-based information to mainstream climate change and variability into their respective strategies policies, and development agendas. To be efficient and effective, interventions should be designed through partnerships, integrating basic

development, food security, and community stability goals, and focused on context-specific situations. As the climate-conflict nexus is complex and therefore highly multidisciplinary, there is a need to build on and strengthen existing networks, and to expand them to include researchers from the global south and affected countries. CGIAR's global network is a unique asset for stimulating dialogue among peace and security and food systems practitioners, researchers, and policymakers, as it represents a diverse set of expertise on the interlinkages between climate, peace and security.

Conclusion

There is very strong evidence that climate variability leading to the failure of food systems is an important driver of conflict in many places. Food systems fail for many, often mutually-reinforcing reasons, very often linked to climatic variables: significant reductions in agricultural production leading to reduced employment, incomes and food availability; degradation of natural resources, reducing livelihood opportunities; and weak government and civil society institutions that are unable to compensate for climate-induced disasters. However, currently there is a disconnect between those attempting to manage responses to natural and man-made disasters by providing humanitarian relief, and researchers who are developing knowledge and tools that could improve the effectiveness of responses to disaster and strengthen resilience of communities in the face of adversity. In this context, this paper has identified the potential of food systems science to contribute to peacebuilding. Institutions in this field such as the CGIAR are well positioned to play a key role in providing new tools and solutions to address knowledge gaps in climate change and food security for peace and security policies and operations. Examples include its capacity to approach the climate-food systems-conflict nexus from a systems perspective, enabling identifying how multiple drivers interact along multiple impact pathways. This knowledge can be used to design more effective intervention strategies that address the underlying issues. Other examples include its success in developing affordable climate information and index insurance packages; its package of climate-smart agricultural technologies and practices; and its approaches to linking conflict reduction with reverses in forest degradation.

Supporting information

S1 Table. Driver categories and definitions used in portfolio analysis.

S2 Table. Conflict categories and definitions used in portfolio analysis.

S3 Table. Webinar titles and speakers.

S1 Protocol. Protocol for CGIAR portfolio analysis on the climate-security nexus.

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Supplementary materials

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