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Co-Benefits and Synergies between Food Security and Eight Positive Peace Pillars

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Abstract: Nowadays, food insecurity (FI) remains one of the most challenging issues due to the complexity of food systems and its structural and underlying causes including governance, economic and production issues, demographical and social issues, and climate/environment, aligning with the four dimensions of sustainable development (economic, social, environmental, and institutional). Regarding to this, when constructing any potential solutions, it is important to identify the fundamental needs, key actors, and major priorities. In speaking of peace, impacts of conflicts (CF) are major drivers of food insecurity, including agricultural damage, food system & production disruptions, crops and livestock plundering, and assets and income loss. Conversely, food insecurity can undermine peace and trigger conflicts with various factors fueled by rapid increase in food prices, limited accesses to food, food supply chain disruption, etc. To understand this nexus better, this study conducts a systematic bibliometric analysis of the literature on food security and the eight pillars of Positive Peace. We searched the Web of Science database, applying stringent inclusion criteria focused on articles detailing interactions between specific food security dimensions (availability, accessibility, utilizaiton, stability) and the eight pillars of Positive Peace (functional government, equitable resources, free information flow, neighborly relations, human capital, rights acceptance, low corruption, sound business environment.). From an initial pool of 123 records, 27 articles met the criteria for full analysis. Findings highlight strongest interactions: (1) Availability-Positive Peace/Conflict (e.g., GM crops); (2) Accessibility-Equitable Distribution of Resources (water/land access) & Food Accessibility/Food Insecurity-Positive Peace/Conflict (e.g., COVID lockdowns); (3) Availability-Governance/Equitable Distribution of Resources (e.g., food aid) & Food Insecurity-Governance (e.g., effective institutions). This analysis provides evidence-based pathways for designing integrated solutions that simultaneously strengthen food security and foster durable peace.

Keywords: food security; positive peace; co-benefits; food systems; sustainable development

1. Introduction

It is argued that humanity is approaching the critical turning point and facing various unprecedented challenges in short human history, while many global challenges need a holistic world-wide solution due to their multidimensionality and complexity which require a global scale cooperation and novel ways of thinking [1]. Since peace is the precondition of humanity's survival in this century, it has embodied in every human being's interests

especially for policy makers and researchers who have been being putting a lot of efforts in searching strategies and solutions for global challenges [2]. To understand the means of building sustainable peace and provide an optimal positive peace environment for prospering humanity, IEP introduced the positive peace index (PPI) consists of eight pillars, each considering three indicators [3], providing a benchmark for effectively evaluate a country's capacity to develop and sustain peace as well as a tool for monitoring a country's status and aiding policy designs and interventions.

On the other hand, food security issues remain one of the most difficult global challenges nowadays due to the complexity of food systems and its structural and underlying causes including governance, economic and production issues, demographical and social problems, and climate/environment, aligning with the four dimensions of sustainable development (economic, social, environmental, and institutional). Regarding this, when constructing any potential solutions to food insecurity and food system sustainability, it is important to identify the fundamental needs, key actors, and major priorities.

Food security (FS) and positive peace (PP) are entangled at various levels with different impacts directly and indirectly [4]. The complexity of food systems and its structural and underlying causes, such as governance, economic and production issues, demographic and social issues, and climate/environment, make FS issues one of the most challenging global challenges of our time. These issues align with the four dimensions of sustainable development (economic, social, environmental, and institutional). In speaking of peace, impacts of conflicts are major drivers of food insecurity, including agricultural damage, food system & production disruptions, crops and livestock plundering, and assets and income loss [5]. Conversely, food insecurity can undermine peace and trigger conflicts with various factors fueled by rapid increase in food prices, limited accesses to food, food supply chain disruption, etc. However, little research has been done on how food security and constructive peace affect one another. Understanding how food security and positive peace interact is essential to creating resilient, peaceful societies that maintain sustainability and decent food security. In order to provide insights and methods for creating solutions to food security and peace concerns, this study will conduct a bibliographic analysis to examine the co-benefits and synergies between the four food security pillars and the eight positive peace pillars.

1.1. Four Pillars of Food Security

FS is defined as "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" at the World Food Summit in 1996 [6]. Correspondingly, food insecurity means lacking access to sufficient good, healthy, and culturally appropriate food [7]. According to the Food and Agriculture Organization [8], food security consists of four dimensions or pillars include food availability, food accessibility, food utilization, and food stability (Figure 1). Each pillar has different determining variables interacting with various factors (Table 1).

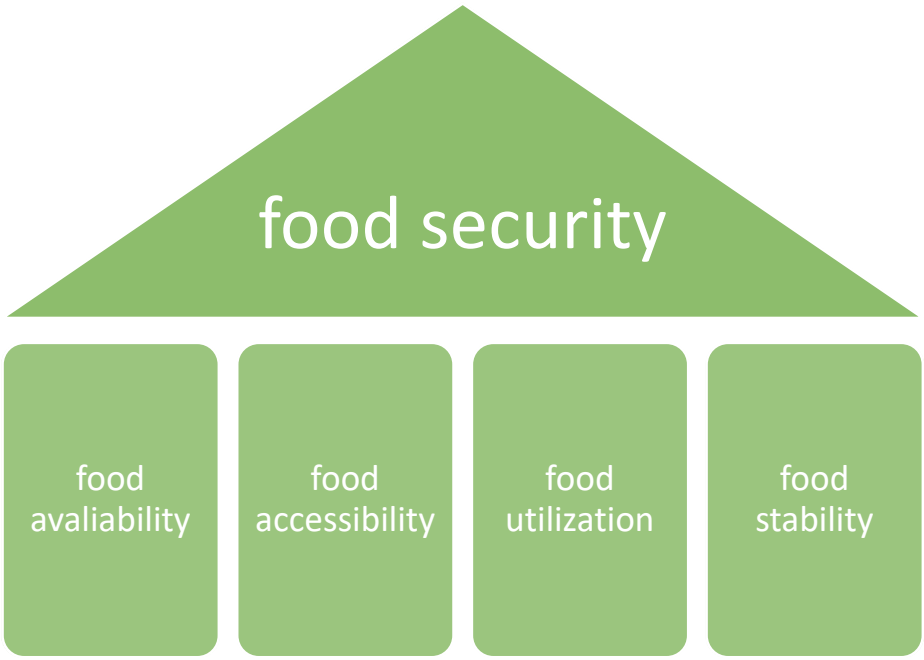

Figure 1. Four pillars of food security (Source: the authors redrawn from [8]).

Table 1 illustrates some examples of FS determinants in different sustainable development dimensions. It shows that not all the FS pillars have determinants across all the four dimensions such as food availability and food accessibility. Also, Table 1 indicates that food stability builds upon all the other pillars, making it the most susceptible pillar to unexpected shocks and changes.

Table 1. Examples of Food Security determinants in different dimensions (Note: gray colour indicates absence or no presence of the topic in the matrix).

FS Pillars	Environmental /Ecological	Economic	Social/Cultural	Institutional /Political
Food Availability: reliable supply of food of sufficient quantity and quality	weather variability; seasonality; climate change	Import capacity; domestic production		Food aid; political instability
Food Accessibility: individuals & households have adequate resources to obtain appropriate food		Affordability; price fluctuations	Equitable distribution; income/purchasing power; marginalized & ethnic groups	Transport and market infrastructure; food distribution; political instability
Food Utilization: food is nutritious and can be adequately metabolised and used by the body	Food quality/nutrition, clean water	Clean water, healthcare, and sanitation; proper preparation	Food taboos; proper preparation; nutritional knowledge/education; care, feeding, and health seeking practices	Food safety and quality
Food Stability: permanent and durable access to food	All determinants and risks can impact the other three pillars over time: e.g., price fluctuations, political instability, climate change,			
Food security (FS): "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life".				

1.2. Eight Pillars of Positive Peace

PP is defined as "the attitudes, institutions and structures that create and sustain peaceful societies" while negative peace refers to "the absence of violence or fear of violence" [9]. According to IEP (2022), PP is made up with eight pillars, namely, they are well-functioning government, equitable distribution of resources, free flow of information, good relations with neighbours, high levels of human capital, acceptance of the rights of others, low levels of corruption, and sound business environment [9]; providing the basis for assessing resilience and fragility, and predicting the possibility of conflict, violence and instability; which all have great potentials to impact and threaten food security (Figure 2).

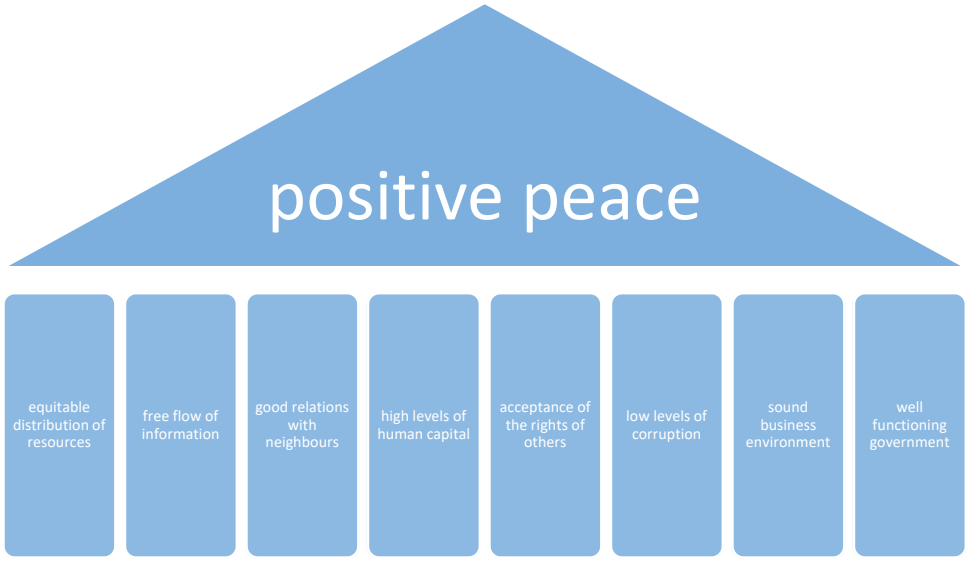

Figure 2. Eight positive pillars of positive peace (Source: the authors redrawn from [9]).

Furthermore, IEP (2022) claims that PP pillars are greatly interconnected and interact in diverse and complicated ways [9]. Hence, when considering PP and FS together, more sophisticated, and complex ways of linking and interaction are expected. Table 2 displays some examples of PP involved in FS pillars, it can tell that some PP pillars do not have connections with all FS pillars while well-functioning government (WF) and sound business environment (SB) are assumed to have various types of relationships with all four pillars of FS. However, the mutual effects of food security and positive peace is not well explored. To build peaceful and resilience societies that sustain good FS and sustainability, understanding the interactions between FS and PP is critical. Thus, this study will explore the co-benefits and synergies between four PP pillars and eight PP pillars through a bibliographic analysis, providing insights and strategies for constructing solutions to food security and peace issues. Peace is commonly discussed in the field of conflict management but remains largely absent from research on food sustainability and food security—particularly in relation to positive peace. Just as curative and preventive measures are both essential to health, negative and positive peace represent complementary dimensions of peace [10]. As Ali & Lin (2010) stated, conflict is a kind of negative peace [11]. Since most of included studies didn't literally discuss PP, thus contents related to conflict are also considered in the literature search. Section 2 describes method and material applied in this study. Results and discussions of the bibliometric analysis are presented in Section 3, followed by a short conclusion on the findings and implication in Section 4.

Table 2. Examples of Pillars of PP involved in pillars of FS (Note: white colour indicates absence or no presence of the topic in the matrix).

PP	Food Availability	Food Accessibility	Food Utilization	Food Stability	FS
Well-Functioning Government	Food aid; Political instability	Transport and market infrastructure; food distribution; political instability	Food safety and quality	Price fluctuations; political stability	
Equitable Distribution of Resources	Food aid	Food distribution		political stability	
Free Flow of Information		Affordability; income/ purchasing power	nutritional knowledge/education; proper preparation	political stability	
Good Relations with Neighbours			care, feeding, and health seeking practices		
High Levels of Human Capital	Food production	income			
Acceptance of the Rights of Others		Equitable distribution; income/ purchasing power; marginalized & ethnic groups	Food taboos; care, feeding, and health seeking practices		
Low Levels of Corruption		Transport and market infrastructure		political stability	
Sound Business Environment	Food production; Import capacity	Affordability	Food safety and quality	Less price fluctuations; political stability	
Positive Peace (PP): "the attitudes, institutions and structures that create and sustain peaceful societies"					

While Table 2 illustrates examples of how PP pillars relate to FS, it is important to clarify why Positive Peace provides a meaningful framework for this analysis. Unlike negative peace, which only considers the absence of conflict, Positive Peace addresses the structural, social, and institutional factors that sustain long-term stability. For instance, well-functioning governance ensures fair food policies and crisis response; equitable distribution of resources improves access to food for marginalized populations; and strong human capital and social cohesion enhance agricultural productivity and food utilization. By integrating PP into FS analysis, this study captures both direct and indirect influences on food availability, accessibility, utilization, and stability, offering a more comprehensive understanding of resilient food systems.

2. Methods and Materials

This study consists of five major steps as shown in Figure 3. After the development of search string, initial search was conducted. All the related studies were retried online from the Web of Science database. During the literature selection stage, the inclusion criteria and exclusion criteria were applied to refine the results. Key information related to PP, FS as well as conflicts were extracted and recorded into Microsoft Excel sheets for further analysis. After that, bibliographic analysis of were conducted by VOSviewer (version:1.6.16(0)).

Figure 3. Research flow (Source: the authors).

The initial search string was "TS = (("food security") AND ("peace" OR "positive peace") AND ("tradeoff*" OR "trade-off*" OR "conflict" OR "synergy" OR "synergies" OR "co-benefit*" OR "cobenefits*" OR "interaction*" OR "inter-relationship*" OR "interrelationship*"))" which only yielded 38 articles. To improve the results, a broader search string was applied:

TS = (("food security" OR "food" OR "food availability" OR "food accessibility" OR "food access" OR "food utilization" OR "food stability") AND ("peace" OR "positive peace") AND ("tradeoff*" OR "trade-off*" OR "conflict" OR "synergy" OR "synergies" OR "co-benefit*" OR "cobenefits*" OR "interaction*" OR "inter-relationship*" OR "interrelationship*" OR "free flow of information" OR "well-functioning government" OR "equitable distribution of resources" OR "good relations with neighbours" OR "high levels of human capital" OR "acceptance of the rights of others" OR "low levels of corruption" OR "sound business environment"))

The initial search was conducted on 15 December 2021 on the Web of Science database and yielded 123 items. After that, the alert function was activated to cover the latest published papers in this study, and further 1 article (updated on 20 December) were added (the cut-off date is 24 January 2022).

The abstracts of the retrieved documents were reviewed for checking whether meet following the two inclusion criteria:

- Covers one or more FS pillars in details or FS or food insecurity generally
- Covers one or more PP pillars in details or peace or conflicts generally

After scanning the abstracts, 34 articles meet the inclusion criteria for full-text review. During the process of full-text review, documents were reviewed for checking whether meeting the following the exclusion criteria:

- Does not discuss any co-benefits/synergies/interactions/relationships between FS (or food insecurity)/one or more four FS pillars and PP (or conflict)/one or more eight PP pillars.

After reviewing the full articles, no additional articles from the reference list of included articles, seven articles meet the exclusion criteria are excluded, 27 documents that have discussed any types of interactions between adaptation and mitigation were selected to be included in the review. Finally, 27 articles remained in the databases. Although the final sample comprised just 27 articles, this limitation is itself significant as it reveals a critical gap in the literature on the food security–peace nexus. Future research is needed to expand the scope, deepen the empirical evidence, and validate the findings across diverse contexts.

3. Results and Discussion

3.1. Overview of the Literature

In this paper, 27 articles were selected for in-depth analysis. Appendix A illustrates the detailed publication title, authors' names, and publication year of included studies [11–37]. It can tell that most studies are published after 2010 and some of their topics talked about war and conflicts rather than peace or positive peace.

Based on the results from Appendix B, it can tell that none of the included studies have discussed positive peace (PP) directly but peace or sustainable peace only. Instead of peace or PP, most of those studies cover the negative peace in terms of conflicts, wars, and violence. Moreover, no studies examined factors related to low levels of corruption (LL) and only very limited discussions on good relations with neighbours (GR) and high levels of human capital (HL) were explored in the included studies. Among all the eighter pillars of PP, it seems that Equitable distribution of resources (ED) and well-functioning government (WF) are most critical influential factors regarding to conflicts and peace as they have drawn the most attention of research interests. As for FS, the most frequently discussed pillars are food availability (AV)**,** followed by food accessibility (AC) and FS in general. This might because AV and AC are the fundamental pillars of most FS while majority of covered contexts are far from other pillars as most included studies are focusing on post-conflicts and/or peace-building situations. In addition, other factors/determinants related to FS pillars that has been investigated in included articles are mainly the opposite of FS—food insecurity (FI) while a few studies even discussed FS and FI together and use them interchangeably. It can be argued that considering both sides of one issue is optimal to provide a more critical and helictical overview for reducing the biases and avoiding blind spots.

3.2. Bibliographic Analysis

This study employed four types of bibliometric analysis: co-occurrence analysis of keywords (Figure 4), author co-citation analysis (Figure 5), source co-citation analysis (Figure 6), and country bibliographic coupling (Figure 7).

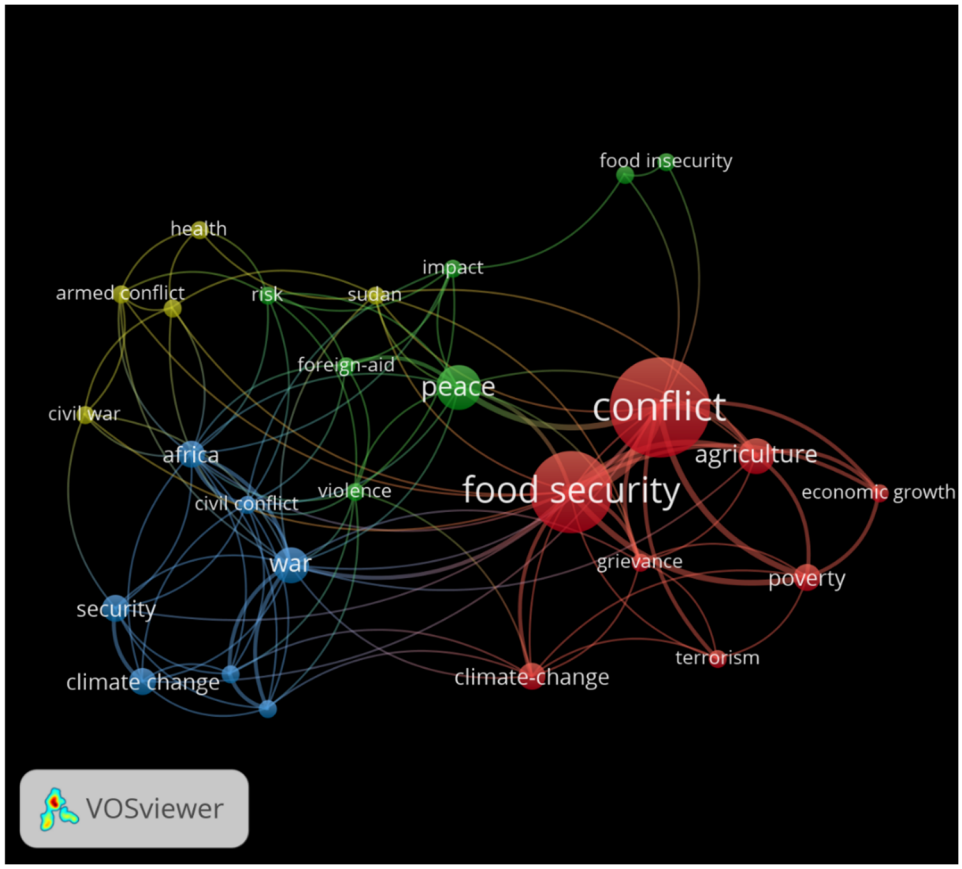

Figure 4. The co-occurrence map.

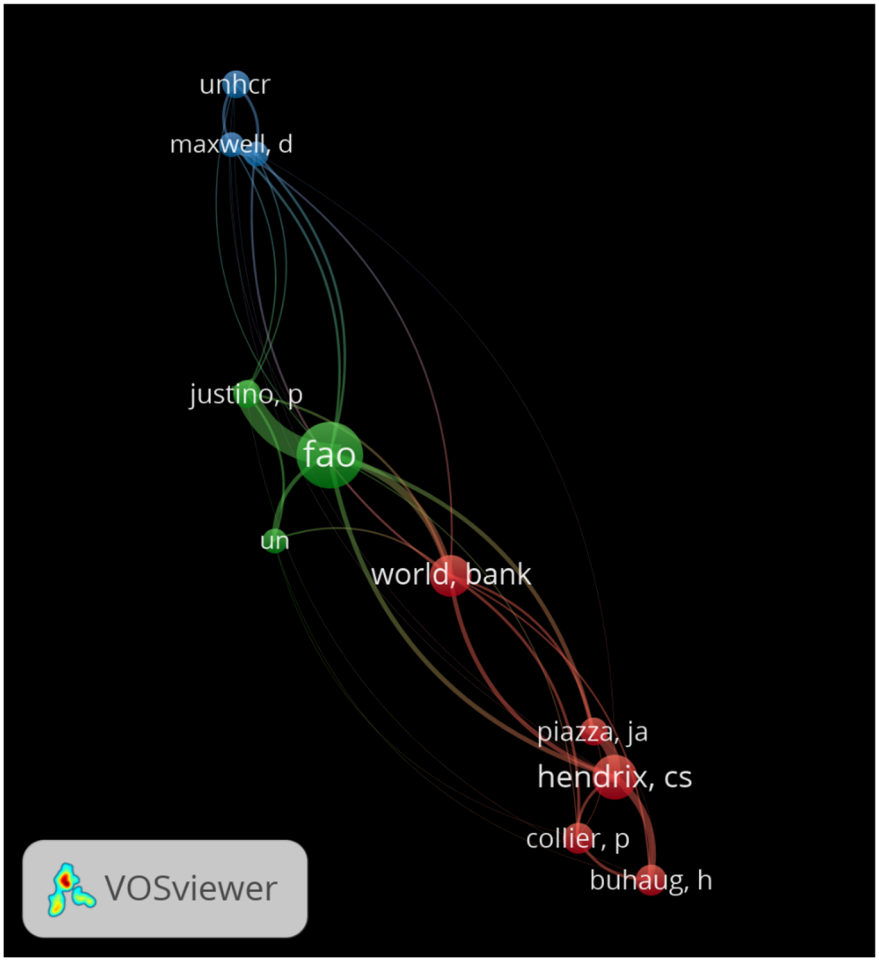

Figure 5. The co-citation by author map.

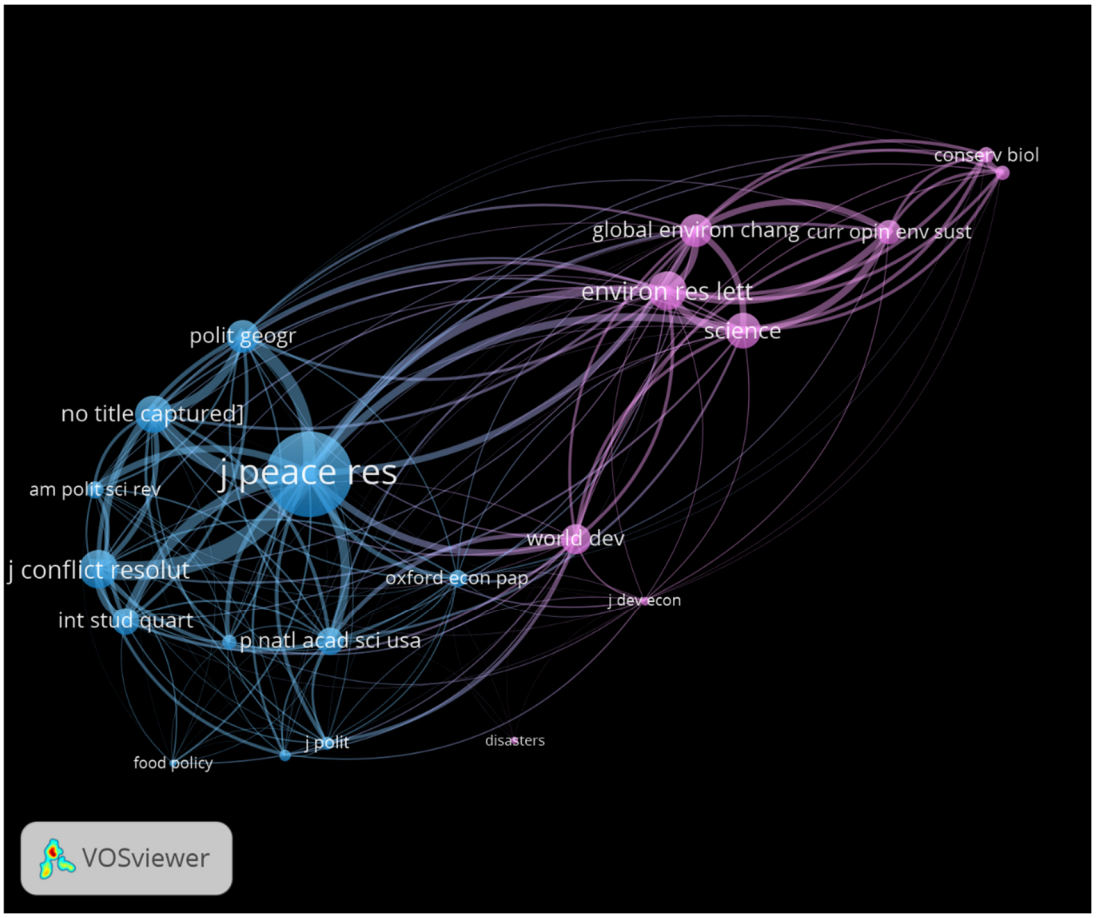

Figure 6. The co-citation by cite source map.

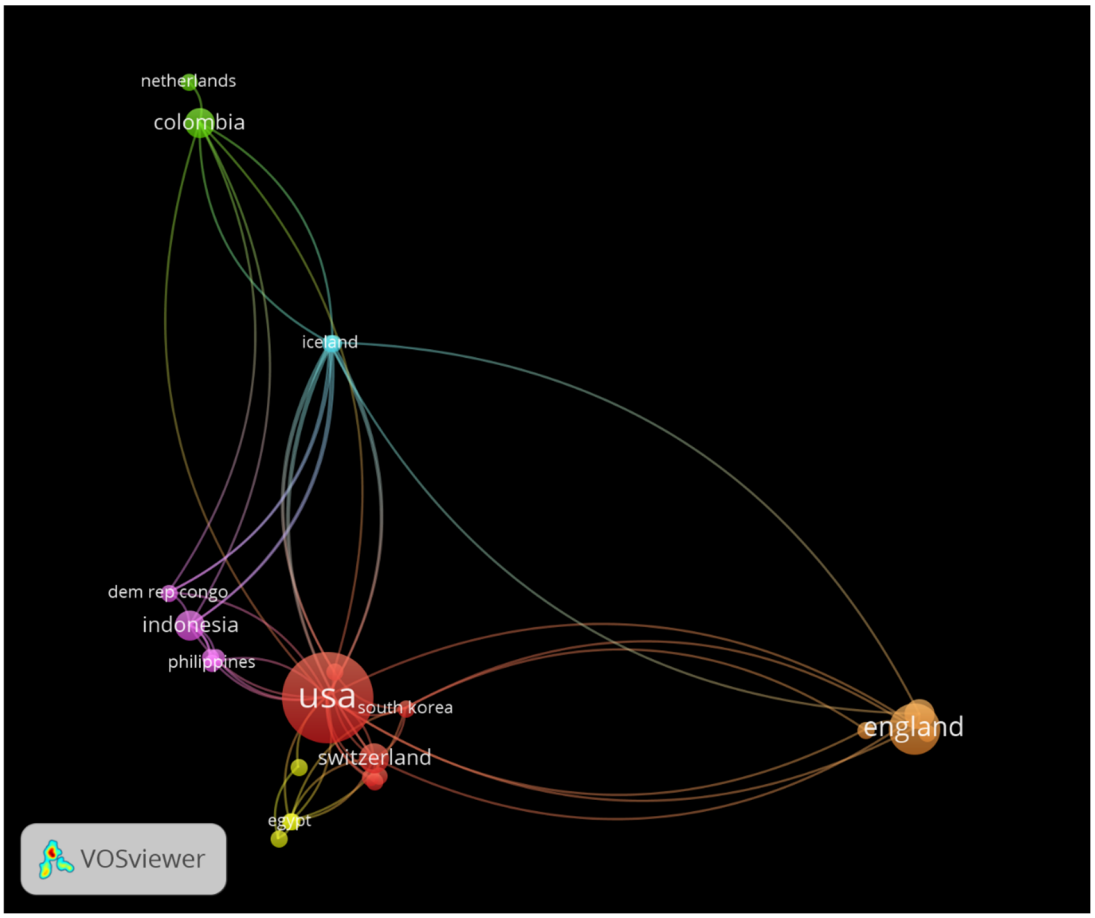

Figure 7. The bibliographic coupling by countries map.

The output of co-occurrence analysis of keywords is illustrated in Figure 4. Using a threshold of four occurrences, 27 keywords were identified and grouped into four clusters. "Conflict" and "food security" emerged as the most dominant and strongly linked terms, with related clusters highlighting themes of governance, peace, climate change, poverty, and regional case studies such as Sudan. This reflects the strong academic focus on the conflict–food security nexus.

Author co-citation analysis is illustrated in Figure 5 above. With a minimum of seven citations, key influential authors included FAO, Hendrix, Justino, and the World Bank. Their prominence underscores the mix of institutional and individual contributions shaping the field.

Figure 6 demonstrates the output of source co-citation analysis. Two main clusters of journals were identified: social-political sciences (e.g., *Journal of Peace Research*, *Journal of Conflict Resolution*) and environmental sciences (e.g., *Environmental Research Letters*, *Science*). This confirms the interdisciplinary nature of food security and peace research, with the top four sources being *Journal of Peace Research*, *Journal of Conflict Resolution*, *Environmental Research Letters*, and *Science*.

Figure 7 illustrates the output of country bibliographic coupling. The USA emerged as the most influential country, with strong collaborations across multiple regions. Other leading contributors include England, Switzerland, and Colombia. Six country clusters were identified, reflecting diverse geographical engagement, but with the USA holding the dominant position.

3.3. Co-Benefits, Synergies, and Nexuses between PP and FS

In this section, detailed discussion on relationships and linkages between four pillars of FS and eight pillars of PP will be provided in each subsection respectively. The segment division is based on Table 2 from Section 1.2 and Appendix B.

To provide a quantitative overview of the literature, we summarize the distribution of studies examining interactions between FS dimensions and PP pillars. Out of the 27 included studies, 14 (52%) addressed food availability, 8 (30%) focused on food accessibility, 2 (7%) on food utilization, and 2 (7%) on food stability. Among studies on food availability, 10 examined conflicts, 3 focused on peace, and 1 on post-conflict peacebuilding. For food accessibility, 6 studies focused on conflicts, while 2 explored connections to peace. The small number of studies on utilization and stability limits quantitative generalization but highlights the research gap in linking these FS pillars with positive peace. Summary tables (Tables 3–6) present the frequency of interactions and associated PP pillars, providing a descriptive, semi-quantitative foundation for the subsequent analysis.

Building on this overview, the following subsections (Sections 3.3.1–3.3.5) discuss the key co-benefits, synergies, and nexuses between each FS pillar and relevant PP pillars, highlighting patterns that emerge across conflicts, peace, and post-conflict contexts. This approach allows us to systematically connect the quantitative summary with qualitative insights from the literature.

3.3.1. Food Availability and PP Pillars

Out of 27 studies included in this study, 14 (52%) covered aspects of food availability when discussing peace or conflicts (Appendix B). Only three studies aim at peace, and one is for post-conflict peacebuilding. The rest are all related to negative peace or in other words, conflicts, and wars. According to Table 3, there are two pillars of PP have connections with food availability in this study: well-functioning government (WF) and equitable distribution of resources (ED). On the other hand, peace as a whole and conflicts as negative peace, also have close connections with food availability in all three terms of co-benefits, synergies, and nexuses.

Table 3. Food availability and PP pillars (Note: white colour indicates absence or no presence of the topic in the matrix).

Food Availability	Co-Benefits	Synergies	Nexuses
Well-Functioning Government	Food subsides on basic foodstuffs		Climate finance for conserving forests; Governmental relief operations in sufficient;
Equitable Distribution of Resources	Food aid; Humanitarian food aid		Good rural road or rail links
PP or CF	Damage on food production; nhimbe-related agricultural activities; Genetically Modified Biotechnological crops; bushmeat	Displacement and migration; difficult access of humanitarian assistance	US food aid; Temperature-induced maize yield decrease; cropland increase

It's undoubtable that governmental intervention and/or institutional efforts play an important role in both building peace and enhancing food security. Fielding & Shortlan (2010) claim that food subsides on basic foodstuffs can reduce conflict intensity [15]. With less and smaller conflict intensity, food availability and function of government will be easier to improve, indicating the co-benefits of food subsides on basic foodstuffs. Moreover, it is found that climate finance for conserving forests to reduce emissions have benefits in both long-lasting peacebuilding and sustainable (low carbon) food production [16]. Another nexus identified by this study are related to government response during the war time. Macrae & Zwi (1992) argue that if governments fail to initiate appeals and facilitate relief operations in sufficient time when food production and marketing systems is attacked during the food war, lack of adequate food will be observed [25].

As for the equitable distribution of resources, the key factors identified are food aid and transportation. Keen & Lee (2007) argue that conventional agriculture is very vulnerable to extreme weathers and continuing conflicts; good rural road and rail links will promote agriculture production while using food aid may offer opportunities to legitimize dysfunctional and violent development process [22]. It is observed that a 10% increase in humanitarian food aid per capita decreases the incidence of civil conflict by about 0.2% point (or by about 0.9% at the mean conflict incidence) while humanitarian food aid is particularly effective in Africa and when facing weather-related food shortage and high ethnic tensions (Mary & Mishra, 2020) [26].

However, it is argued that food aid has the opposing effects on the countries with a recent history of civil conflicts, Nunn & Qian (2014) claim that the incidence and duration of civil conflicts will be increased with an increase in US food aid [29].

Lastly, the linkages between conflicts and food available have been deeply investigated. Conflicts destroy land, water, seeds, and other resources for food production, resulting in lack of food availability [28]. Additionally, a country's natural resource variables are significant predictors of its risk for violent conflict and food production is identified as the most interactive natural resource variable which impact food availability directly [33]. *Nhimbe* is an inclusive community mechanism with various agricultural activities like land preparation, shelling of grain, sowing of seeds, ox-drawn ploughing, and planting [34] It is widely used for improving household food security in Zimbabwe, contributing to conflict prevention and peacebuilding in the communities [34]. Another thing/factor benefit to peace and food availability is genetically modified (GM) crops, especially those with improved heat and drought tolerance, greater nutritional value, and resistant to pests, may have even stronger alleviating effects on food insecurity and political conflict [35]. When considering mitigating conflicts, Szenkovics et al. (2021) argue that no positive effects on food insecurity can be expected without using GM crops as a factor [35]. Bushmeat as an alternative food source has the similar function. In the Democratic Republic of Congo, it is observed that bushmeat is like an important safety net for conflict-affected urban populations, contributing the provisioning of basic food needs and post-conflict peace building efforts [37].

Furthermore, Sassi (2021) claims that conflicts and food insecurity cause more displacement and migration during and after the conflict time, while making humanitarian assistance more challenging in remote rural areas [32]. Besides this, other elements related to food production also form different nexuses. It is argued that climate-induced maize yield decrease will reduce food production and increase the incidence of civil conflict in Egypt [20]. While cropland increase affect food availability and conflicts in a different way. According to Koren & Bagozzi (2017), cropland increase the frequency of violence during the conflict time while pacifying effect is observed during the peace time [23].

In short, the pillars of PP interacting with food availability identified in this study are WF and ED while most interactions are related to conflicts. Different types of food aid during the time of peace and conflict pose different influences. The most common type of interaction is nexus, indicating that multiple actors and agents are involved in this complicated process.

3.3.2. Food Accessibility and PP Pillars

Out of 27 studies included in this study, 8 (30%) covered aspects of food accessibility when discussing peace or conflicts (Appendix B). As mentioned earlier, most articles investigate conflicts rather than peace, only two articles connect peace/sustainable peace to food accessibility. As shown in Table 4, no studies cover any straight synergies between food accessibility and PP pillars while the interactions related to the following 5 pillars are discussed in the included studies: WF (well-functioning government), ED (equitable distribution of resources), FF (free flow of information), AR (acceptance of the rights of others), and SB (sound business environment) with conflicts.

Table 4. Food accessibility and PP pillars (Note: white colour indicates absence or no presence of the topic in the matrix).

Food Accessibility	Co-Benefits	Synergies	Nexuses
Well-Functioning Government			agreements over access to water and land
Equitable Distribution of Resources	Food aid; Humanitarian food aid		agreements over access to water and land; Poor transport networks
Free Flow of Information			Poor information networks; the collapse of markets
Acceptance of the Rights of Others	improving youth skills in agriculture and entrepreneurship		Agreements over access to water and land
Sound Business Environment	improving youth skills in agriculture and entrepreneurship		The collapse of markets
PP or CF			Foodcost; the collapse of markets; US food aid; the lockdown measures introduced to prevent the COVID-19 pandemic

According to Justino et al. (2020), enhancing youth skills in a in agriculture and entrepreneurship while supporting their access to markets will have benefits in reducing unemployment and sustaining peace [21]. Also, this may further require and enhance positive peace pillars of AR and SB. Meanwhile, markets connect with SB and FF closely. It offers opportunities for making business and information exchange while supporting people's access to food. Macrae & Zwi (1992) state that the collapse of markets is a significant indicator in evaluating the impacts of civil wars on food security [25].

Secondly, it is argued that the brokering of agreements over access to water and land not only contributes to decreasing conflicts and structural cultural inequalities but also have multiple benefits in enhancing food accessibility and ensuring equitable access. It relies on WF and AR pillars of positive peace while promote FS, ED and AR in turn [24]. For enhancing ED, food aid also plays a vital role in food distribution. Mary & Mishra (2020) claim that humanitarian food aid improves food accessibility and ED while reduce the incidence, commencement, and duration of both small-scale and large-scale civil conflicts [26]. Yet, Nunn & Qian (2014) find it differently, their research unreal that US food aid extends the duration of small-scale civil conflicts and indeed promotes civil conflict on average [29].

As mentioned in previous section, traditional agriculture and food production are very vulnerable to continuing conflict, Keen & Lee (2007) point out that food price differences vary extremely due to poor transportation and information networks, implying that promoting the pillars of ED and FF in conflicts-affected regions are important to maintain affordable and reasonable food price so as food accessibility [22]. Ali & Lin (2010) argue that civil conflicts can positively affect the foodcost while international are not. With higher foodcost, food accessibility is expected to decrease [10]. Currently, security food security especially food accessibility is threatened by the cumulative effect of violence, the growing impacts of climate shocks on food production decrease and the dramatic impacts of COVID-19 pandemic lockdown strategies on food price increase [32]. Moreover, it can be argued that COVID-19 lockdown strategies undermine the PP pillars of ED and FF, hence weaken the overall positive peace.

In a word, this study finds that food accessibility has a wide range of interactions with PP pillars. The most frequent type of interaction is nexus while some actors/factors have multiple impacts across various pillars such as agreements over access to water and land, the agriculture and entrepreneurship skills of youth, showing that catalysts, actors, determinants, outcomes of those connections are interwind together with multiple sets of functions and effects.

3.3.3. Food Utilization and PP Pillars

Out of 27 studies included in this study, only 2 (7%) covered aspects of food utilization and both studies mainly focused on conflicts (Appendix B) while only GR (good relations with neighbours) pillar are covered (Table 5). As states in Section 3.3.1, the *Nhimbe*-related agricultural activities can prevent conflict and build peace in communities [34]. Besides those activities related to food production, it also involves food processing which can improve food utilization while enhance social cohesion in communities as well as familial relationships [34]. On the other hand, it is known that some GM crops have higher nutrition values, better tastes, longer length of

preservation and preparation-friendly features, all contributing to promoting better utilization. Moreover, Szenkovics et al. (2021) also argue that GM crops are the most influential factors than population growth and climate change in reducing in reducing food insecurity and political conflicts [35]. In short, since most of included studies are focused on conflicts whose primary concerns are always the most fundamental pillars of FS (i.e., food availability and accessibility), the exploration on interactions between food utilization and PP pillars are limited.

Table 5. Food utilization and PP pillars.

Food Utilization	Co-Benefits	Synergies	Nexuses
Good Relations with Neighbours	Nhimbe-related agricultural activities		
PP or CF	Nhimbe-related agricultural activities; GM crops		

3.3.4. Food Stability and PP Pillars

Food stability depends on social and political stability, it's directly linked to conflicts. While most included studies cover conflicts, this section only focuses other factors influencing food stability and peace. Out of 27 studies included in this study, only two (7%) covered aspects of food stability and all are related to conflicts (Appendix B). Since food stability requires the long-term maintenance of the three pillars, it can be regarded as the most sensitive pillar while is hardest pillar to achieve. Besides political stability, another key aspect has instant and significant impacts on food stability is market stability which is related price stability.

Table 6 shows that only the well-functioning government (WF) pillar are discussed in relation to food stabiltiy, others are all focusing on PP or CF generally. According to Fielding & Shortlan (2010), decreasing subsidies on basic foodstuffs have significant impacts on conflicts, for example, cutting food subsidies result in increasing bread price, and further a growing incidences of Islamist violence is witnessed in the following months [15]. Furthermore, Ali & Lin (2010) define the foodcost as the portion of incomes paid to the food sector versus total manufacturing earnings [11]. They claim that civil wars can positively affect foodcost while food while an increasing in foodcost result in decreasing food affordability and food stability. On the top of that, the results imply that connections between PP and food stability are inherited from the interactions from the other three pillars of FS. Main actors, agents, players, and catalysts involved in those interactions related to food stability are similar and connected to each other.

Table 6. Food stability and PP pillars (Note: white colour indicates absence or no presence of the topic in the matrix).

Food Stability	Co-Benefits	Synergies	Nexuses
Well-Functioning Government	Food subsides on basic foodstuffs		the price of bread rises
PP or CF			foodcost

3.3.5. FS and PP Pillars

Out of 27 studies included in this study, 14 covered aspects of food availability when discussing peace or conflicts (Table 4). Except one discussed the livelihood interventions supported by the United Nations High Commissioner for Refugees (UNHCR), the rest are all focusing on conflicts.

It is evident that conflicts form most of the leading causes of decreasing food security while food security has multiple benefits of reducing the likelihoods of conflicts, building, and sustaining long-term peace in both pre-conflict and post-conflict periods [17]. Since a lot of agriculturally dependent countries are suffering from persistent violent conflicts, Szenkovics et al. (2021) claim that here is a straightforward correlation between food insecurity and conflicts [35]. Moreover, persistent conflicts and wars, governmental mismanagement, and lacking access to the land and markets are identified as the trigger of long-lasting trend in declining food production and growing poverty [18]. To resolve and reverse this trend, Jenick & Grofova (2015) suggest series strategies including enhancement of the institutional efficiency, promotion of governmental effectiveness, improvement of the country's economy diversity etc [18]. According to Sassi (2021), acute food insecurity nowadays results from the collective effects of civil conflicts and violence, climate change shocks, and dramatic price increase due to the lockdown approach for COVID-19 pandemic control [32]. With respect to this situation, the significance of promoting livelihood strategies, strengthening the household's' capitals (i.e., human, natural, physical, and

financial) as well as establishing sound institutions while promoting their inclusiveness has been emphasized for alleviating food insecurity and growing violence [32].

On the other hand, natural resource variables of a nation are recognized as principal forecasters of its probability and incidence for conflicts and wars while access to water and food security are the most significant natural resource feature in predicting conflicts [33]. This implies the close connections between FS, PP, and ED (Equitable Distribution of Resources) which can benefit to conflict inhibition and remediation. Additionally, climate change, urbanization, migration, and food insecurity are recognized as key influential factors of conflicts by Szenkovics et al. (2021) [35]. It is argued that GM crops can modify determinants of food insecurity extensively and even diminish food security issues directly, meanwhile GM crops also offer opportunities to enhance food security and eventually minimize political conflicts in developing countries [35].

Regarding to peacebuilding and food security improvement in remote fragile areas, livelihood interventions carried by UNHCR with supports from VSLAs (Village Saving and Loan Association) in terms of emergency fund and loans are found to be incredibly successful in South Sudan [36]. Those livelihood interventions consist of agricultural production and marketing, entrepreneurship and business, and occupational skills training [36], indicating that educational trainings to residents living in remote vulnerable areas can provide the knowledge, tools, and fundamental to FS, FF, and SB respectively.

Like food accessibility and food stability, the most common type of interactions between FF and PP identified by this study is nexus. As shown in Table 7 there are five pillars of PP have connections with FS or FI due to convolution, complexity, comprehensiveness of their interactions. More specifically, they are WF, ED, FF, HL (high levels of human capital) and SB (sound busines environment).

Table 7. FS and PP pillars (Note: white colour indicates absence or no presence of the topic in the matrix).

FS or FI	Co-Benefits	Synergies	Nexuses
Well-Functioning Government			Effective state institutions; promotion of sound and inclusive institutions; diverse economy on national scale
Equitable Distribution of Resources			Lack of access to the land; religious stratification
Free Flow of Information			Education; lack of access to markets
High Levels of Human Capital		reinforcement of all the forms of capital	
Sound Business Environment			Lack of access to markets
PP or CF	GM crops; UNHCR-supported livelihood interventions		Lack of access to the land and markets; the lockdown measures introduced to prevent the COVID-19 pandemic

4. Summary and Conclusions

The main result of this study is demonstrated in Figures 8 and 9. Besides the interactions between PP and/or conflicts and FS and/or food insecurity, it is shown that well-functioning government (WF: dark blue) and equitable distribution of resources (ED: orange) are the most interactive factors related to FS and its pillars. This highlights the critical role of governments in developing PP and FS and reflect the nature of food is a resource which requires equitable distribution for greater impacts. The third most influential factor is free flow of information (FF: grey), followed by sound business environment (SB: brown), acceptance of the rights of others (AR: green), while good relations with neighbours (GR: yellow) and high levels of human capital (HL: light blue) have the same significance which has only one interaction identified. The least relative PP pillar is low levels of corruption (LL), no discussions exist on its connections with FS pillars, FS, or food insecurity.

On the other hand, this study finds food accessibility (AC) has the most active association with most PP pillars (Figure 8). Meanwhile, FS and food insecurity only rank the second for their interactions with factors of multiple PP pillars and conflicts. Food availability (AV) has the greatest total numbers of interactions like AC but only involves two PP pillars, and PP/CF. Interactions identified by the included studies only cover a little on both food utilization (UT) and food stability (ST), indicating that their dependence on the other two pillars as prerequisites, especially during the time of conflicts and wars.

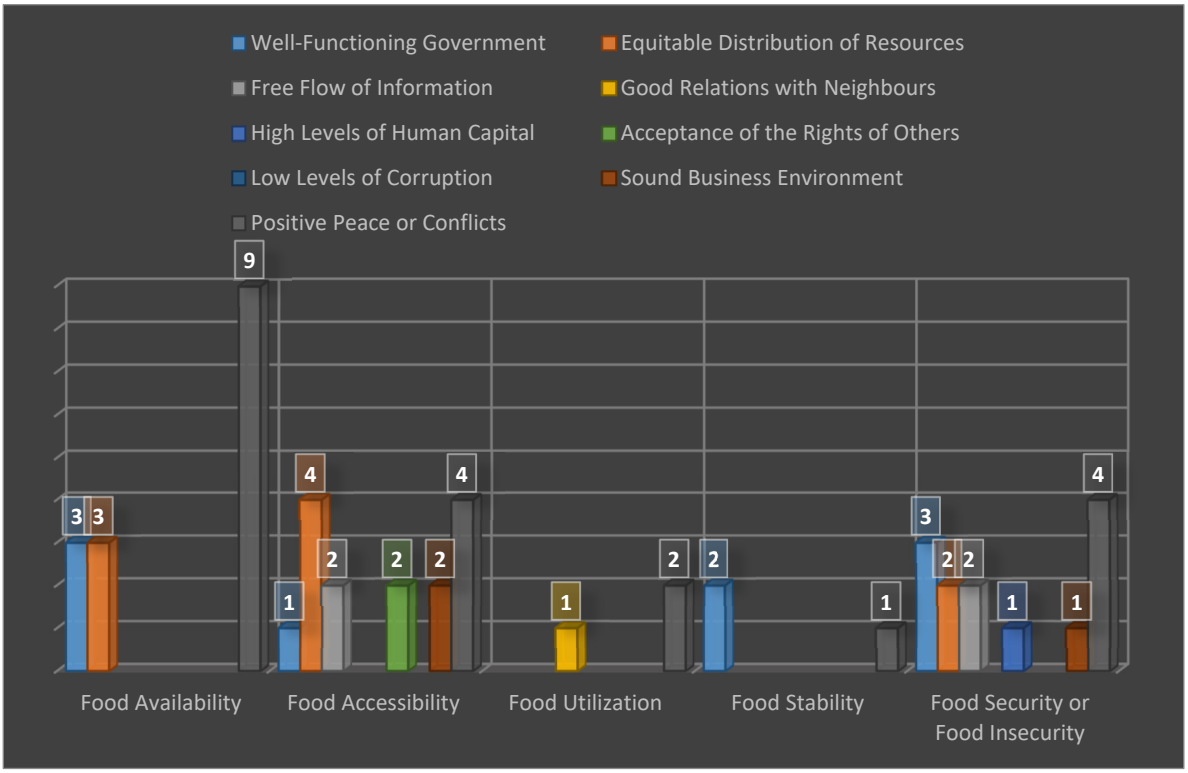

Figure 8. The distribution of interactions between pillars of PP and FS.

In sum, this study examines 27 articles covering PP, FS, food insecurity (FI), and conflicts (CF) in depth, revealing that only limited articles focus on peace or PP. The most popular keywords related to PP and FS studies are conflicts, food security, peace, war, climate change, Africa, and agriculture while the most influential authors are FAO, Hendrix, Justino, and World Bank. The highly influential journals belong to two different main areas: social and political, natural, and environmental. Furthermore, the most influential journals are Journal of Peace Research. Also, the most influential countries are USA and England.

With respect to the total number of interactions identified for each pillar in the analysis, the most significant interactions are between AV-PP/CF (e.g., GM crops); followed by AC-ED (e.g., food aid, agreements over access to water and land), AC-PP/CF (e.g., US food aid, COVID-19 lockdown), and FS/FI-PP/CF (e.g., COVID-19 lockdown). AV-WF (e.g., food subsides on basic food stuffs), AV-ED (e.g., food aid), FS/FI-WF (e.g., Effective state institutions) interactions are the third powerful interactions. Other interactions with similar importance are AC-FF (e.g., information networks, markets), AC-AR (e.g., improving youth skills in agriculture and entrepreneurship), AC-SB (e.g., improving youth skills in agriculture and entrepreneurship), UT-PP/CF (e.g., GM crops), ST-WF (e.g., food subsides on basic food stuffs), FS/FI-ED (e.g., lack of access to the land;), FS/FI-FF (e.g., lack of access to markets, education). The least vital interactions are between AC-WF (e.g., agreements over access to water and land), UT-GR (e.g., Nhimbe-related agricultural activities), ST-PP/CF (e.g., foodcost), FS/FI-HL (e.g., reinforcement of all the forms of capital), and FS/FI-SB (e.g., lack of access to markets). It can tell that some of the determinators, factors, or actors have multiple impacts, influences, and roles across those various interactions, the most influential variables among them including lack of access to water and land, lack of access to markets, GM crops, food subsides, food aid, Nhimbe-related agricultural activities, and COVID-19 lockdown.

Furthermore, the interactions between food security and positive peace differ across national contexts. In conflict-affected or developing countries, pillars such as government functioning and acceptance of the rights of others are critical for ensuring basic food security. In more stable or developed contexts, equitable resource distribution and human capital may play a stronger role. These heterogeneities suggest that interventions to improve food security and peace should be tailored to the specific socio-political and developmental conditions of each country, highlighting the need for context-sensitive policies and strategies [38,39].

Based on the interpretations of result, the recommendations for different conditions are illustrated in Figure 9 below.

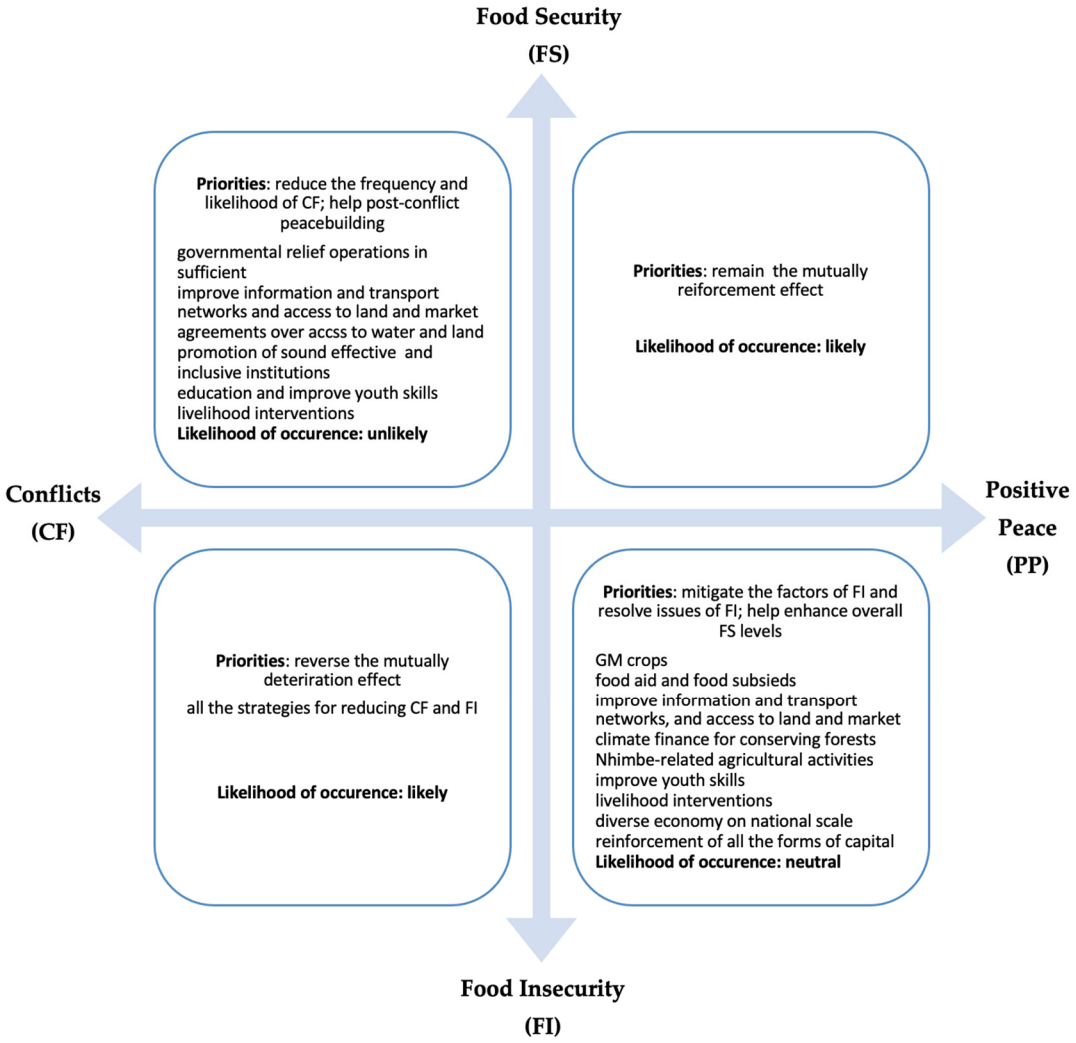

Figure 9. Recommendations for different settings.

Author Contributions

Conceptualization, T.Z. and A.C.; Methodology, T.Z., and A.C., Formal Analysis, T.Z. and A.C.; Writing—Original Draft Preparation, T.Z.; Writing—Review and Editing, A.C.; Supervision, A.C.; Project Administration, T.Z. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data described in the manuscript, code book, and analytic code will be made available upon request pending [e.g., application and approval, payment, other].

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Conflicts of Interest

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

Appendix A

Table A1. List of Included studies.

ID#	Authors	Year	Title
1	Ali & Lin [11]	2010	Wars, food cost and countervailing policies: A panel data approach
2	Bellinger & Kattelman [12]	2021	Insects for peace
3	Bowles et al. [13]	2015	Domestic terrorism in the developing world: role of food security
4	Castro-Nunez [14]	2018	Climate change, conflict, and health
5	Fielding & Shortland [15]	2010	Responding to Climate Change in Tropical Countries Emerging from Armed Conflicts: Harnessing Climate Finance, Peacebuilding, and Sustainable Food
6	Greent et al. [16]	2018	'An eye for an eye, a tooth for a tooth': Political violence and counterinsurgency in Egypt
7	Jenick & Grofova [17]	2014	Armed Conflict in Central America and Immigrant Food Insecurity in the United States
8	Jenick & Grofova [18]	2015	The least developed countries - the case of the Congo DR
9	Jones et al. [19]	2017	Least developed countries - characteristics
10	Jun [20]	2017	Food scarcity and state vulnerability: Unpacking the link between climate variability and violent unrest
11	Justino et al. [21]	2020	Temperature, maize yield, and civil conflicts in sub-Saharan Africa
12	Keen & Lee [22]	2007	Pathways to achieving food security, sustainable peace, and gender equality: Evidence from three FAO interventions
13	Koren & Bagozzi [23]	2017	Conflict, trade and the medium-term future of food security in Sudan
14	Lander & Richards [24]	2019	Living off the land: The connection between cropland, food security, and violence against civilians
15	Macrae & Zwi [25]	1992	Addressing Hunger and Starvation in Situations of Armed Conflict—Laying the Foundations for Peace
16	Mary & Mishra [26]	2020	Food as an Instrument of War in Contemporary African Famines—A Review of the Evidence
17	Matus [27]	2007	Humanitarian food aid and civil conflict
18	Messer & Cohen [28]	2015	The future of food security in the Three Areas of Sudan
19	Nunn & Qian [29]	2014	Breaking the Links Between Conflict and Hunger Redux
20	Pingali et al. [30]	2005	US Food Aid and Civil Conflict
21	Pomeroy et al. [31]	2007	Food security in complex emergencies: enhancing food system resilience
22	Sassi [32]	2021	Fish wars: Conflict and collaboration in fisheries management in Southeast Asia
23	Schellens & Belyazid [33]	2020	Coping Strategies of Food Insecure Households in Conflict Areas: The Case of South Sudan
24	Sithole [34]	2020	Revisiting the Contested Role of Natural Resources in Violent Conflict Risk through Machine Learning
25	Szenkovics et al. [35]	2021	Nhimbe practice in Zimbabwe revisited: Not only a method of socio-economic assistance but also a communal mechanism for conflict prevention and peacebuilding
26	Vallet et al. [36]	2021	Can genetically modified (GM) crops act as possible alternatives to mitigate world political conflicts for food?
27	Van Vliet [37]	2017	Where are the development actors in protracted crises? Refugee livelihood and food security outcomes in South Sudan demonstrate the potential for fragile settings

Appendix B

Table A2. Distributions of included articles' coverage of PP and FS Pillars.

ID#	PP	ED	FF	GR	HL	AR	LL	SB	WF	Other	FS	AV	AC	UT	ST	Other
1										Civil wars						Food cost
2										PC						FI
3										PC						FI
4										Long-lasting PC						Sustainable (low-carbon) food production
5										Violent political CF						Food subsidies
6										Armed CF						FI
7										CF						FI
8										CF						FI
9										Violent CF						Climate-induced FI
10										Civil CF						Crop's yield, sufficient food supply
11										Sustainable PC						Food distribution system
12										PC						Agriculture, FI
13										Violence, CF, PC						FI, cropland increases
14										Violence, CF						FI
15										wars						
16										Civil CF						Humanitarian food aid
17										wars						FI
18										CF						FI
19										Civil CF						US food aid
20										CF						Food emergency
21										Resource CF						
22										Armed CF, intercommunal violence						FI
23										CF						Food production
24										CF						nhimbe-related agricultural activities
25										Political CF						GM crops
26										Interventions supported by UNHCR						
27										CF, post-CF PC building						FI, bushmeat
TOTAL	0	6	5	1	1	2	0	2	6	27	7	14	8	2	2	24

Note: FI: food insecurity; PC: peace; CF: conflicts; UNHCR: the United Nations High Commissioner for Refuge; Green and/ blue highlighted mean articles covered that pillar of PP/FS.

References

1. UN. Transforming Our World: The 2030 Agenda for Sustainable Development. 2015. Available online: https://sdgs.un.org/2030agenda (accessed on 23 May 2024).
2. Institute for Economics & Peace. *Positive Peace Report 2020: Analysing the Factors That Sustain Peace*; Institute for Economics & Peace: Sydney, NSW, Australia, 2020.
3. Amadei, B. Revisiting positive peace using systems tools. *Technol. Forecast. Soc. Chang.* **2020**, *158*, 120149.
4. Besa, S.T. The Nexus between USAID-Funded Food Security Programs and Positive Peace: A Case of Ensure Program, Buhera. Unpublished Thesis (Bachelor's Thesis), Midlands State University, Gweru, Zimbabwe, 2017.
5. Bora, S.; Ceccacci, I.; Delgado, C.; et al. *Food Security and Conflict*; World Bank: Washington, DC, USA, 2011.
6. Matemilola, S.; Alabi, H. A. Food security. In *Encyclopedia of Sustainable Management*; Springer International Publishing: Cham, Switzerland, 2021; pp. 1–5.
7. Moffat, T.; Mohammed, C.; Newbold, K.B. Cultural dimensions of food insecurity among immigrants and refugees. *Hum. Organ.* **2017**, *76*, 15–27.
8. Food Security: Pillars, Determinants and Factors Affecting It—Public Health Notes. Available online: https://www.publichealthnotes.com/food-security-determinants-and-urbanization/ (accessed on 30 June 2022).
9. Institute for Economics & Peace. *Positive Peace Report 2022: Analysing the Factors That Build, Predict and Sustain Peace*; Institute for Economics & Peace: Sydney, NSW, Australia, 2022.
10. Galtung, J. Cultural violence. *J. Peace Res.* **1990**, *27*, 291–305.

11. Ali, H.E.; Lin, E.S. Wars, Foodcost and Countervailing Policies: A Panel Data Approach. *Food Policy* **2010**, *35*, 378–390. https://doi.org/10.1016/J.foodpol.2010.05.004.
12. Bellinger, N.; Kattelman, K.T. Domestic Terrorism in the Developing World: Role of Food Security. *J. Int. Relat. Dev.* **2021**, *24*, 306–332. https://doi.org/10.1057/s41268-020-00191-y.
13. Bowles, D.C.; Butler, C.D.; Morisetti, N. Climate Change, Conflict and Health. *J. R. Soc. Med.* **2015**, *108*, 390–395. https://doi.org/10.1177/0141076815603234.
14. Castro-Nunez, A. Responding to Climate Change in Tropical Countries Emerging from Armed Conflicts: Harnessing Climate Finance, Peacebuilding, and Sustainable Food. *Forests* **2018**, *9*, 621. https://doi.org/10.3390/f9100621.
15. Fielding, D.; Shortland, A. "An Eye for an Eye, a Tooth for a Tooth": Political Violence and Counter-Insurgency in Egypt. *J. Peace Res.* **2010**, *47*, 433–447. https://doi.org/10.1177/0022343309360897.
16. Greent, J.C.; Boakye, E.A.; Barnidge, E.K.; et al. Armed Conflict in Central America and Immigrant Food Insecurity in the United States. *J. Epidemiol. Glob. Health* **2018**, *8*, 59–64. https://doi.org/10.2991/j.jegh.2018.02.005.
17. Jenicek, V.; Grofova, S. Least Developed Countries—Characteristics. *Agric. Econ.* **2014**, *60*, 65–73. https://doi.org/10.17221/67/2013-AGRICECON.
18. Jenicek, V.; Grofova, S. The Least Developed Countries—The Case of the Congo DR. *Agric. Econ.* **2015**, *61*, 135–148. https://doi.org/10.17221/49/2014-AGRICECON.
19. Jones, B.T.; Mattiacci, E.; Braumoeller, B.F. Food Scarcity and State Vulnerability: Unpacking the Link between Climate Variability and Violent Unrest. *J. Peace Res.* **2017**, *54*, 335–350. https://doi.org/10.1177/0022343316684662.
20. Jun, T. Temperature, Maize Yield, and Civil Conflicts in Sub-Saharan Africa. *Clim. Chang.* **2017**, *142*, 183–197. https://doi.org/10.1007/s10584-017-1941-0.
21. Justino, P.; Hagerman, K.; Jackson, J.; et al. Pathways to Achieving Food Security, Sustainable Peace and Gender Equality: Evidence from Three FAO Interventions. *Dev. Policy Rev.* **2020**, *38*, 85–99. https://doi.org/10.1111/dpr.12413.
22. Keen, D.; Lee, V. Conflict, Trade and the Medium-Term Future of Food Security in Sudan. *Disasters* **2007**, *31*, S9–S24. https://doi.org/10.1111/j.1467-7717.2007.00346.x.
23. Koren, O.; Bagozzi, B.E. Living off the Land: The Connection between Cropland, Food Security, and Violence against Civilians. *J. Peace Res.* **2017**, *54*, 351–364. https://doi.org/10.1177/0022343316684543.
24. Lander, B.; Richards, R.V. Addressing Hunger and Starvation in Situations of Armed Conflict—Laying the Foundations for Peace. *J. Int. Crim. Justice* **2019**, *17*, 675–698. https://doi.org/10.1093/jicj/mqz055.
25. Macrae, J.; Zwi, A.B. Food as an instrument of war in contemporary african famines—A review of the evidence. *Disasters* **1992**, *16*, 299–321. https://doi.org/10.1111/j.1467-7717.1992.tb00412.x.
26. Mary, S.; Mishra, A.K. Humanitarian Food Aid and Civil Conflict. *World Dev.* **2020**, *126*, 104713. https://doi.org/10.1016/J.WORLDDEV.2019.104713.
27. Matus, J. The Future of Food Security in the Three Areas of Sudan. *Disasters* **2007**, *31*, S91–S103. https://doi.org/10.1111/j.1467-7717.2007.00351.x.
28. Messer, E.; Cohen, M.J. Breaking the Links Between Conflict and Hunger Redux. *World Med. Health Policy* **2015**, *7*, 211–233. https://doi.org/10.1002/wmh3.147.
29. Nunn, N.; Qian, N. US Food Aid and Civil Conflict. *Am. Econ. Rev.* **2014**, *104*, 1630–1666. https://doi.org/10.1257/aer.104.6.1630.
30. Pingali, P.; Alinovi, L.; Sutton, J. Food Security in Complex Emergencies: Enhancing Food System Resilience. *Disasters* **2005**, *29*, S5–S24. https://doi.org/10.1111/j.0361-3666.2005.00282.x.
31. Pomeroy, R.; Parks, J.; Pollnac, R.; et al. Fish Wars: Conflict and Collaboration in Fisheries Management in Southeast Asia. *Mar. Policy* **2007**, *31*, 645–656. https://doi.org/10.1016/j.marpol.2007.03.012.
32. Sassi, M. Coping Strategies of Food Insecure Households in Conflict Areas: The Case of South Sudan. *sustainability* **2021**, *13*, 8615. https://doi.org/10.3390/su13158615.
33. Schellens, M.K.; Belyazid, S. Revisiting the Contested Role of Natural Resources in Violent Conflict Risk through Machine Learning. *Sustainability* **2020**, *12*, 6574. https://doi.org/10.3390/su12166574.
34. Sithole, P.M. Nhimbe Practice in Zimbabwe Revisited: Not Only a Method of Socio-Economic Assistance but Also a Communal Mechanism for Conflict Prevention and Peacebuilding. *Afr. J. Confl. Resolut.* **2020**, *20*, 115–134.
35. Szenkovics, D.; Tonk, M.; Balog, A. Can Genetically Modified (GM) Crops Act as Possible Alternatives to Mitigate World Political Conflicts for Food? *Food Energy Secur.* **2021**, *10*, e268. https://doi.org/10.1002/fes3.268.
36. Vallet, M.E.; Frankenberger, T.R.; Presnall, C.; et al. Where Are the Development Actors in Protracted Crises? Refugee Livelihood and Food Security Outcomes in South Sudan Demonstrate the Potential for Fragile Settings. *World Dev. Perspect.* **2021**, *24*, 100366. https://doi.org/10.1016/J.WDP.2021.100366.
37. Van Vliet, N.; Schulte-Herbruggen, B.; Muhindo, J.; et al. Trends in Bushmeat Trade in a Postconflict Forest Town: Implications for Food Security. *Ecol. Soc.* **2017**, *22*, 35. https://doi.org/10.5751/ES-09780-220435.
38. Van Eck, N.J.; Waltman, L. VOSviewer Manual. Available online: https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.6.pdf (accessed on 21 June 2022).
39. Sharifi, A. Co-Benefits and Synergies between Urban Climate Change Mitigation and Adaptation Measures: A Literature Review. *Sci. Total Environ.* **2021**, *750*, 141642.