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Entry

Food, Climate Change, and the Challenge of Innovation

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Definition: Climate change is a shift in the climate's condition that lasts for an extended period, usually decades or longer, and that may be detected by changes in the mean and variability of its parameters. The full spectrum of players and their related value-adding activities, that are a part of the food supply chain, including the disposal of food items derived from agriculture, forestry, or fisheries, are collectively called food systems. Food systems are a component of their larger economic, social, and environmental contexts. Finally, food security is the condition in which all individuals consistently have physical and financial access to adequate safe, nutritious food that satisfies their dietary needs and food choices for an active and healthy life. Climate change and its relationships with food systems and security are complex since food systems significantly contribute to climate change. However, climate change impacts food systems unpredictably, leading to food insecurity through adverse impacts on the four dimensions of food security: utilization, access, food availability, and stability. Climate change adaptation plans are urgent and include measures such as flood and climate protection, waste management and recycling, climate-smart agriculture, and analytical climatic conditions innovation equipment on agricultural processes and activities. Nevertheless, addressing the climate crisis and its adverse impacts on food security through the activation and promotion of innovation needs reliable information and intervention in many different but interconnected fields, such as institutional design, philanthropy, novel partnerships, finance, and international cooperation. In this context, this paper analyses the relationship between climate change, agriculture, and global–local strategies to ensure food security and also discusses policies' role in fostering innovation for supporting local agro-food systems and their capacity to sustain societal needs.

Keywords: climate change; food systems; food security; agriculture technology

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1. Introduction

Climate change is one of the biggest world concerns. It imposes impacts and costs on society and the environment, thus conditioning the possibilities of life and development for present and future generations [1]. Its manifestations are diverse: on the one hand, the primary manifestations of climate change are physical (e.g., rainfall, increased frequency of extreme weather events, changes in temperature, and sea levels); on the other hand, the secondary manifestations are much more diverse and not as easily predictable, including ecological, social, and economic consequences [2,3]. Moreover, its effects do not have similar impacts on the whole of the world population as it presents more severe consequences in certain most vulnerable groups or areas, many of them also characterized by problems of scarcity of food or periods of frequent famines. This is the case in some developing countries, where the subsistence of millions of people is highly dependent on activities closely linked to sectors significantly exposed to climate change, such as agriculture and livestock farming. This population is more vulnerable to climate change risk as they have precarious economic conditions that reduce their financial and technical capacities to deal with it and its consequences. Then, the trajectories of poverty reduction and the efforts to ensure food security are undermined [4–6].

The relationship between climate change, agriculture, and global–local strategies to ensure food security appears increasingly complex. It is affected and continually reshaped by changing political and economic factors, requiring more profound analysis and discussion at the research and institutional levels to identify strategies for reducing climate change vulnerability and stabilizing food security levels [7,8]. With this background, this work seeks first to define the framework of a specific analytical approach to the above relations. Then it discusses policies' role in fostering innovation for supporting the local agro-food systems and their capacity to sustain societal needs. In this case, the focus is on the analysis of food security, not solely considering the availability of food but also the other three dimensions of food security, access, stability, and utilization [9].

The adoption of the so-called food system approach helps in identifying the importance of considering different scales and levels of interaction [10]. This system was built upon the consideration that food systems are intrinsically multiscale, multilevel, and multidimensional. Therefore, in promoting mitigation and adaptation measures as innovation strategies it is important to recognize multiscale and multilevel interactions. Food system vulnerabilities, in connection with climate change, are interrelated and combined across scales, levels, and dimensions. Vulnerabilities in various spheres of the same food system may involve synergies. As a result, innovations for mitigation and adaptation relating to one level, scale, or dimension may be fostered or slowed down by factors and processes developing at different scales or levels [11,12]. Therefore, innovation is conceived here as a means of changing the food system organization at different scales and levels, either as a response to changes in the spheres connected with it (e.g., ecosystems, socioeconomic systems, etc.) or as a pre-emptive action to influence these environments. This paper focuses on Food Innovation Technologies (FIT) as tools for adapting food systems and agricultural production to climate change.

FIT implies a wide range of innovative elements not limited to specific products or production processes. It also includes new organizational and interaction processes across and within different levels of action and responsibility.

Therefore, innovation is 'broadly defined to encompass a range of types: new product or service, new process technology, new organization structure, administrative systems, or new plans or programs' [13] (p. 694). It also includes the social networks of the actors involved in the interconnected spheres.

This contribution reflects the links between agro-food production, climate change, and innovation. It has an introductory nature in intending to outline the bidirectional relation that connects the evolution of food systems and the long-term shifts in temperatures and weather patterns. It provides a framework for further discussion on the role that innovation and supportive action and policies can play in transforming agro-food production to counter climate change. In this sense, this entry covers the importance that policies have in stimulating innovation for supporting local agro-food systems and their ability to meet societal demands, as well as the relationship between climate change, agriculture, and global–local initiatives to assure food security.

In an increasingly energy-demanding global system, successfully fighting climate change will require, first and foremost, targeted government policies to level the economic playing field between the production of clean energy and the use of more polluting energy sources through actions such as the determination of a price for carbon dioxide emissions [14,15]. However, it also requires policies that encourage the promoting of agro-food innovation in a sustainable, open, and collaborative way.

2. Defining the Approach: Climate Change under the Food System Lens

As previously introduced, food systems are increasingly influenced by climate. They can be considered both "victims" and "co-producers" of the effects of the widespread tendency of climate variability in the medium term, as well as of the consequences of longer-term climate change [16]. The 2022 Global Food Policy Report [17] underlines that elements such as mutable precipitation trends, global sea level rise, and growing frequency and intensity of extreme weather events contribute to reducing—in specific contexts and specific periods—the levels of agricultural productivity. Meanwhile, this undermines the functioning of global and more localized food supply chains and displaces communities in some particular cases [18,19].

In addition, the food systems are responsible for more than a third of the global greenhouse gas emissions (GHG) that cause climate change. For two reasons, agro-food production and transformation are at the center of the attention of environmental activists, researchers, and policymakers. The food system contributes considerably to global warming. However, its multiple internal dimensions are required fields that trigger incisive and synergetic climate change solutions [17]. Looking at specific data, since the 1960s, food supply per capita has increased by more than 30%, followed by the massive introduction of nitrogen fertilizers (about +800%) and water resources for irrigation, with an increase of more than 100% [20]. The Food and Agriculture Organization of the United Nations (FAO) calculates that, by the middle of the 21st century, people will need about 50% more agro-food products to meet the food demand of the expanding world population [21]. Then, this will engender significant increases in GHG emissions and diversified environmental consequences, such as the loss of biodiversity [22].

The worldwide human population has increased by more than three times since the middle of the 20th century, from an estimated 2.5 billion in 1950 to 8.0 billion in mid-November 2022, with additions of 1 billion people since 2010 and 2 billion people since 1998. Since 1950, the number of people has roughly doubled every 37 years, reaching five billion in 1987. The world's population is predicted to double again in over 70 years, reaching over ten billion people by 2059 [23]. These population trends and the increased income levels in many developing countries are determining relevant changes in the global food demand as local and more globalized dietary patterns are now characterized by new requests for a higher presence of meat and other proteins on the family tables [24–26]. In this respect, global food demand is expected to rise between 59% to 98% by 2050; the higher increase is expected especially for food rich in animal calories (between 61% and 144% in the period 2005–2050), caused mainly by two key-factors: the differences in the demand system evolving preferences and orientations and the discrepancies in income levels and price elasticities [27,28].

Currently, livestock production occupies nearly 26% of the available land, while one-third of the cropland supports this animal breeding. This generates about 40% of global agricultural gross domestic product (GDP), providing 33% of the total proteins produced and 17% of the calories consumed worldwide [29,30]. Hence, livestock activities generate essential employment opportunities for rural households. At the same time—more broadly—every day, agriculture produces an average of 23.7 million tons of food, providing livelihoods for over 2.5 billion people [16].

On the other hand, it represents the main economic sustenance for many rural dwellers (e.g., in developing countries, agriculture accounts for 29% of GDP and 65% of employment) (https://www.cbd.int/article/biodiversityforfood-1, accessed on 9 March 2023). Agriculture is undoubtedly the backbone of many national economies; however, as underlined by the authors of reference [16], a significant part of the rural livelihoods is at a varying stage of uncertainty on the front line of climate change. According to projections made at the start of this millennium, by 2050, the average daily energy availability per person could rise to 3050 kcal, or 2970 kcal in developing nations, from 2770 kcal in 2005. Nonetheless, the exact estimation suggested that more production increases would be needed to guarantee adequate food security for everyone [31].

To sum up, food systems' actors can contribute to producing specific positive outcomes supporting food security and, in parallel, generating negative impacts on the environment and climate. Climate change has a composite nexus with food systems, undermining food security through impacts on food security dimensions (i.e., utilization, access, food availability, and stability). According to the High-Level Group on Food Safety and Nutrition of FAO, among the possible consequences of climate change on food security, both direct and indirect effects can be observed in nutrition patterns (e.g., changes in the amount and composition of food consumed, as well as in means, namely changes in employment opportunities and in the cost of acquiring the necessary food for adequate nutrition) [32]. The following Figure 1, elaborated by the authors of reference [33], summarizes these effects.

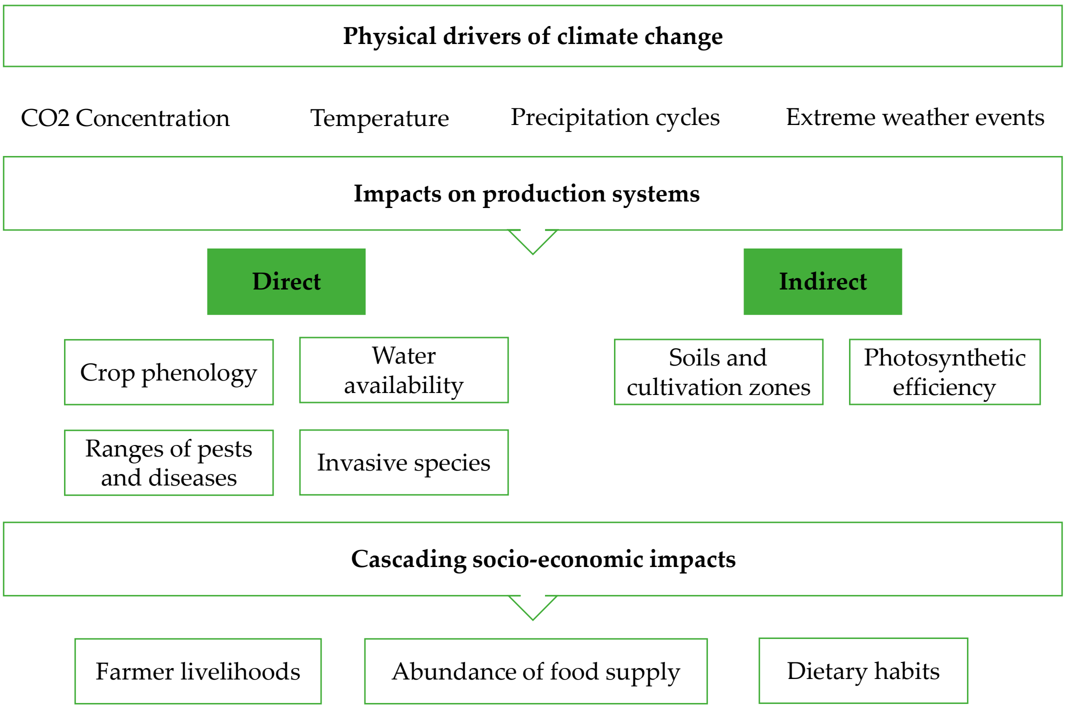

Figure 1. Impacts of climate change on agriculture. Source: [33].

Production levels, both in local and national markets, access to water, the capacity of the country for imports, and food stock conditions, among other elements, affect food availability, which is aggravated due to the increase in the average world temperatures. The effects will be significant in health and forests productivity, regional changes in the distribution and production of marine resources, the proliferation of different types of pests and diseases, losses of biodiversity, and the quality of the functioning of ecosystems in natural habitats or the decline of arable land due to aridity and salinity of groundwater [34].

Another critical element of agriculture is the water supply problem, which would affect the natural resource base on which agricultural activities depend, livestock and fishing, with changes in their production processes due to the adaptability of the land for different types of crops and pastures. The reduction in rains, dry seasons, the severity of the monsoons and tropical rains, and the increase in temperatures mainly affect areas of the tropics and semi-arid tropics, reducing crop potential. Some studies indicate that climate variability affects agricultural yield depending on the crop and the region [35], observing that, in some territories severely hit by extreme climate events (e.g., rising temperatures), despite global growth trends, agricultural productivity has fallen. Some warmer areas of Africa, Latin America, and the Caribbean experienced a drop between 26% and 34% [36]. Secondly, agricultural intensification to reach an increase in production has also generated severe environmental damage through deforestation of grazing lands, loss of soil, pesticide contamination, and the release of greenhouse gasses, thus contributing to the change in global temperatures [37].

The interconnections between the climate, food, ecosystems (water, oceans, and land), and socioeconomic structure are complex and develop at multiple scales, local, regional, and global (Figure 2 elaborated by [20]). It is essential to commonly recognize that the supply of and demand for food is interconnected. Thus, this must be mutually understood and assessed to identify the complex challenges of the mitigation of and adaptation to climate change. A broader integrated framework and strategy for action is necessary, which implies adopting an analysis and action approach with a food system lens. Outcomes, effects, and impacts cannot disaggregate solely, for example, in agricultural production. GHG emissions from agriculture result primarily from 'pull' factors originating in the demand spheres (e.g., dietary choices, market mechanisms, trade relationships, etc.). Therefore, mitigation and adaptation measures require a multi-actor action developing and connecting at—and within—diverse levels.

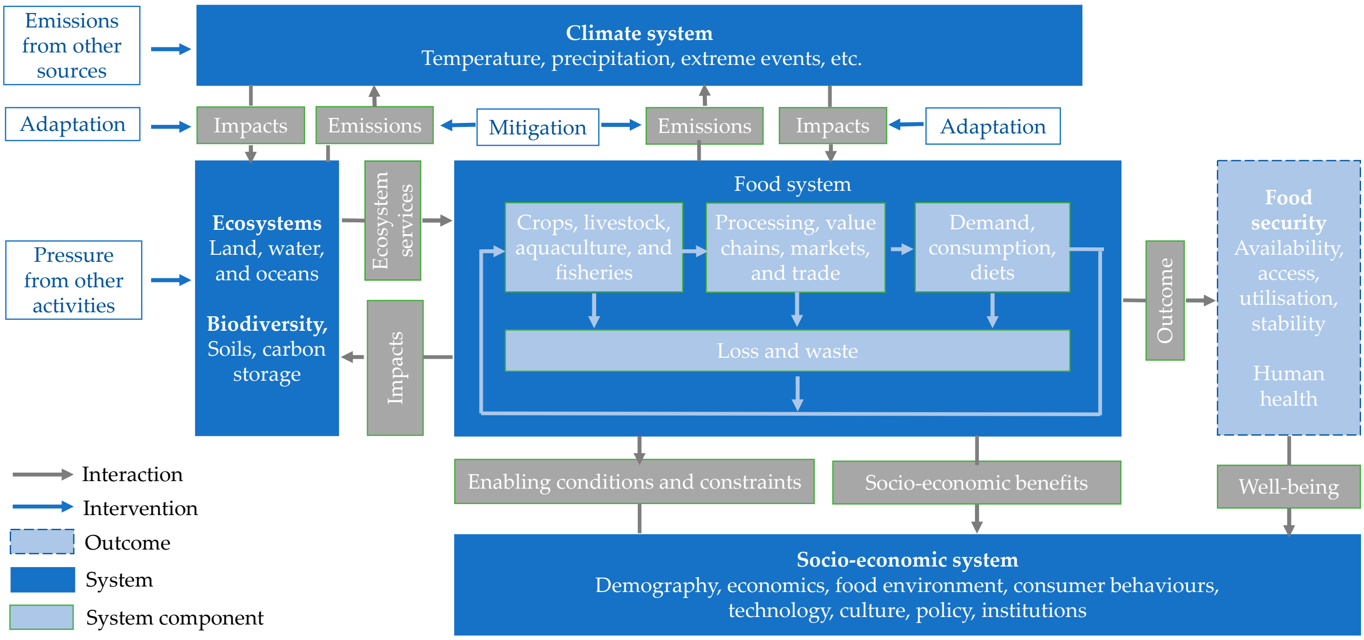

Figure 2. Interlinkages between the climate system, food system, ecosystems, and socioeconomic system. Source: [20].

The food system approach is a framework for analysis and action that offers relevant insights for the implementation of climate change adaptation and mitigation policies since—by clearly identifying and recognizing essential, but not always discussed, links between production, consumer demand, and dietary choices—it supports and facilitates the integration of different actors from institutional entities, businesses, and civil society groups. Furthermore, it is crucial to develop practical strategies for boosting the adoption of necessary adaptation and mitigation measures, such as a thorough analysis of the function of incentives and the quick creation of cutting-edge circular-economy-related approaches [38]. Hence, the food systems approach helps, in a broader way, to provide an agenda for the systematic analysis of trade-offs and synergies, balanced across a range of societal goals, as solving problems of food insecurity must therefore be based upon understanding complex interactions among multiple and often synergic processes [39,40].

3. Threats to Food Security: Understanding the Relationships between Food Security, Food Systems, and Climate Change

There are many drivers through which climate change impacts food systems and, thus, the four dimensions of food security and human health [20]—for example, temperature variations, precipitations, extreme climate events, and other combinations of biophysical variables. The following four subsections will discuss the links between climate change and the dimensions of food security.

3.1. Climate Change Impacts on Food Availability

The definition of food availability is when people have enough food of appropriate quality supplied through domestic production or imports [41]. In recent years, the impacts of climate change on food availability have been further studied, especially on crops, fruits, and vegetables [20,42]. According to the authors of reference [43], at a global scale, climate change negatively affected crop yield, diminishing crop production of maize, wheat, and soybeans. At the same time, the authors of reference [44] argue that heat stress reduces fruit sets of fruiting vegetables and increases the speed of annual vegetables, which provokes a reduction in their photo-assimilation time, causing a decrease in their quality. In addition, drylands constitute over 40% of the earth's land area, and are the habitat for 2.5 billion people [45]. Agriculture in drylands is highly affected by climate change. Notably, developing countries need the technological and financial capacity to keep crops yield, which reduces food availability in those societies [46]. Climate change is also associated with extreme weather events such as rising temperatures, drier seasons, and changes in precipitation. These cause declines and stagnation in crop yields, changes in the agricultural calendar, increased infestation of pests and diseases, and declining viability of crop varieties, reducing the quality and production of crops [47–49]. Incipient evidence shows that climate change also affects pollination services by disrupting biodiversity, especially in insect, bird, and bat populations [50,51]. This situation hinders the productivity and reproduction of agricultural systems.

Every region experiences different effects of climate change on crop output. In Africa, the yield of crops, fruits, and vegetables has declined significantly in recent years, mainly due to its adverse effects on small farmers and the increase in the durability of dry seasons [52]. The timing, severity, and patterns of the annual weather cycle have changed in Latin America's agriculture, reducing agricultural production [53]. In Asia, rice yield has experienced an improvement due to structural adjustment, scientific and technological progress, governmental policies, and regional warming due to climate change [54]. In Europe, the negative impacts of climate change vary depending on the country, but show adverse effects on yield crops over almost all of the continent, especially in southern-western Europe due to the drying trends [55,56].

Livestock is also negatively affected by climate change. On the one hand, heat, cold, and water stress cause physical damage to animals; on the other hand, increasing temperatures, precipitation variation, and carbon dioxide impact livestock environments, such as through a reduction in the quantity and quality of water and feed, modifications in the geographical diseases' distribution, and the destruction of livestock farming infrastructure [57]. All these previous impacts present difficulties in livestock reproduction, cause damage to animal health and reduced livestock productivity, and diminish food availability. The adverse effects of climate change on livestock differ among different countries. Developed countries, with more industrialized systems, suffer more from indirect impacts, such as rises in the cost of water, feeding and feedstuff, and transport [58], while developing countries, especially those with pastoralism systems, suffer more from direct effects, such as mobility, poor animal health, decreasing rangelands, land degradation, conflicts for the access to pasture land, livestock numbers, and declining access to water and feed [59–61]. Given that pastoralism is practiced by around 200–500 million people in more than 75% of countries, this condition poses a threat to food security [62].

3.2. Climate Change Impacts on Food Access

According to FAO (2006), the access dimension of food security means the capacity to obtain food, including buying food at affordable prices. The negative impacts of climate change on access to food act on the demand and supply side. On the one hand, previous studies, such as those conducted by the authors of references [27,63–65], argue that climate change decreases agricultural productivity, reducing food supply, which may lead to price increases. This impact affects consumers, hindering access to food, especially in low- and medium-income countries. In addition, higher prices reduce access to the quantity and quality of food. This situation reduces the intake of critical micronutrients, causing less healthy diets [66].

On the other hand, climate change also negatively affects demand, reducing the salaries of small farmers, and especially women and children, in rural areas [67]. In developing countries, farmers often depend on crops, aquaculture, livestock, and non-agricultural activities to obtain their livelihood [68]. Heat and cold stress, precipitation variations, and extreme seasonal weather decline their animal and agriculture productivity, reducing their income. Finally, this situation hinders farmers' access to food. According to the authors of reference [69], smallholder farming systems, which heavily rely on agriculture and livestock for survival, are said to be particularly sensitive to climate change.

3.3. Climate Change Impacts Food Utilization

The definition of food utilization is the biological utilization of food by the body; it involves a diet providing enough potable water, adequate sanitation, energy, and essential nutrients [41]. Food utilization is influenced by the quality of food and food safety. The former refers to handling, storing, and preparing food to prevent infections and helping to ensure that food keeps enough nutrients for a healthy diet. Climate change events, such as temperature, precipitation, and humidity, change the population dynamics of contaminating organisms, affecting food quality and safety [20]. The impacts of climate change on the biology of contaminating organisms include the production of fungi [70], disruption in aquatic microorganism systems causing diseases, for example, dinoflagellates, breakouts of cold chains, and stored systems producing pests [71]. In drylands, water stores for irrigation can become a significant source of pathogens [72], which could quickly spread through changes in air currents. Moreover, plants are changing their biology to adapt to climate change, impacting healthy human consumption. For example, according to the authors of reference [73], crops sequester more heavy metals, and cassava produces hydrogen cyanide to defend against herbivore attacks.

Climate change also affects food quality through direct effects on plant and animal biology and by increasing CO_2 on biology through CO_2 fertilization [20]. Firstly, climate change affects the metabolic rate in plants and ectothermic animals, changing their growth rates and yields. This situation may lead to producers changing their business strategies, focusing more on reproduction than the food's quality of nutrients. Secondly, the rising concentrations of CO_2 and other GHGs in the atmosphere enhance photosynthesis (CO_2 fertilization). This allows stomata to close partially during gas exchange, reducing water loss through transpiration. These factors affect plants' metabolism, disrupting food quality, growth, and yield rates [74,75].

3.4. Climate Change Impacts Food Stability

The dimension of food stability refers to people's ability to access and use food steadily, without intervening periods of hunger [41,76]. Despite the fact tat the relationship between climate change and the stability of food systems has yet to be further studied, there are some studies, such as that in reference [21], that argue that climate change causes instability in food systems. In this study, FAO analyzed the prevalence of undernourishment (PoU) in countries exposed to extreme climate events. The evidence showed that in countries with a high vulnerability of agriculture production/yields and high PoU sensitivity to severe droughts, the PoU is 9.8 points higher. In addition, the IPCC (2019) points out that the frequency, length, and intensity of some extreme events will rise over the next few decades. The increasing extreme climate change events may occur randomly and reduce future food availability and access to good quality food. Finally, the evolution of climate change is neither stable nor predictable, so neither are its effects on future food systems.

4. The Challenge of Innovation and the Role of Policies

The need for climate change adaptation plans is urgent, considering the negative impacts of climate change on food security and agricultural systems. These plans include strategies such as climate-smart agriculture, water sustainability, waste management and recycling, flood and climate protection, and analytical climate conditions innovation machinery on agricultural processes and activities. FITs are mainly seen as a potential solution [77]. FITs generally focus on how food and new food could be developed, produced, and processed via innovative technology to enhance food quality, safety, and security [78–80]. It is possible to divide FITs into climate change mitigation and adaptation technologies. The former types refer to those technologies that try to reduce and prevent GHG emission and their causes. In contrast, the second one refers to those that try to change the process, practices, and structures of food systems to moderate the potential damages of climate change, and those that try to ascertain whether it is possible to benefit from the opportunities associated with this phenomenon. Some of the following are examples of technologies applied to agriculture with the potential to tackle climate change:

(a) Digital agriculture is also known as smart agriculture or e-agriculture. It refers to digital tools that help collect, store, analyze, and share data or information about relevant agriculture variables. These tools allow farmers to determine the health status of plants and animals in the field, and facilitate the relationships of the actors involved in agriculture, such as farmers and consumers. Some examples of digital agriculture technologies are apps using machine learning to predict food supply and demand in a specific geographical range. On the other hand, sensors for collecting agriculture data, or drones equipped with the internet of things, help to quickly determine the health of a plantation through high-resolution photography [81].

(b) Agriculture 5.0, or artificial intelligence and deep learning, refers to systems that help farmers to detect diseases, pests, and poor nutrition on farms. Sensors can collect information on the field, such as pests, and then decide which herbicide to apply based on the knowledge of the region, types of crops, etc. These solutions are cheap and fast for farmers because they only need a smartphone and help to face climate change, especially for small farmers of low income [82].

(c) Blockchain enables the traceability of information in the food supply chain, helping farmers efficiently and safely use the data collected by smart agriculture systems [83].

(d) Vertical farming is the practice of growing plants in vertical layers. This type of farming often incorporates controlled environment agriculture technologies and farming techniques, such as hydroponics, aquaponics, and aeroponics. Therefore, vertical farming helps to face the negative impacts of climate change on agriculture [84].

Despite these technologies being ways to tackle climate change, they also require expenditure in terms of energy, financial support, and knowledge. Therefore, they still need to be implemented by farmers worldwide, especially in developing countries.

Another critical challenge facing FITs in addressing climate change is the controversy between mitigation and adaptation technologies. Some studies suggest that mitigation and adaptation technologies can be considered substitute technologies, since implementing the mitigation technologies in the present can reduce the necessity for future adaptation. In contrast, future adaptation could compensate for the lack of mitigation technologies implemented today [85,86]. However, despite this controversy, according to the authors of reference [87], the necessity for adaptation and mitigation technologies is a current and future priority. The mitigation–adaptation trade-offs have shown examples of maladaptation, such as energy-intensive desalination technologies to improve water supply or air-conditioning in response to heat waves [88]. According to the authors of reference [77], at least three reasons hinder good equilibriums between mitigation–adaptation trade-offs: (i) firstly, to compare the costs of implementing current mitigation technologies or future adaptation technologies, it is necessary to consider the discount rate, which is empirically controversial. (ii) Secondly, the benefits of adaptation technologies are mostly site-specific and related to a private dimension; on the contrary, mitigation technologies contribute to the determination of conditions and situations which a wide range of people can benefit from, and that can be considered as global public goods. (iii) Thirdly, climate change's economic, social, and environmental impacts are still unpredictable and uncertain so they may be beyond the scope of any available and planned technological solution. Despite these reasons, the authors of reference [77] point out that mitigation–adaptation technologies may complement each other and create co-benefits. Furthermore, suppose disparities in access to digital infrastructure, digital literacy, knowledge access, and the specific gender digital divide are not addressed for all players in the food system. In that case, the promise of organizational innovation and digital technologies to help manage climate-related risks for food systems has yet to be completely realized [17].

Addressing the climate crisis and its adverse impacts on food security through the activation and promotion of innovation needs intervention in many different but interconnected fields, such as institutional design, novel partnerships, finance, international cooperation, and philanthropy, among others [89]. Concerning FITs, unlocking their potential requires, first and foremost, the promotion of investments for bridging the digital divide. On the one hand, public and private interventions should incentivize citizens to familiarize themselves with new technologies by leveraging public awareness campaigns, specific subsidies, training and innovation initiatives, and public agendas. On the other hand, the launch of systems of tax benefits can stimulate private investments in digital infrastructures in rural areas and food production zones. In this regard, means of improving producers' ability to find location-specific climatic information, to interpret data to comprehend hazards, to make decisions, and to make strategic investments are required in this area.

In this sense, the food systems, research communities, and digital climate service actors must coordinate on multiple levels and across various sectors. Moreover, to better address these public supports, there is a need to have robust and integrated information systems that can avoid misguided investments and forms of wasted financial resources. According to the IFPRI (2022), decision-makers can only identify potential risks early, or implement proactive measures to manage risks systematically with accurate and timely data, leaving countries vulnerable to climate shocks. By providing a continuous systematization of high-quality data, research can help governments develop novel frameworks, methods, and integrated tools to characterize and co-define a joint policy on actions to adapt territories to climate change.

Hence, initiatives and programs should be data-driven and co-created through the collaboration of different actors working at different levels and scales of geographical intervention and responsibility. Innovation design systems should be based on an operational governance plan detailing the actors, roles, and responsibility status at each process phase. Data and information providers—within broader innovation strategies—should certify data provenance and quality, following applicable international standards. Moreover, data—related to innovation tools and processes—should be shared and made accessible according to the FAIR (Findable, Accessible, Interoperable, and Reusable) principles [90].

Co-production requires trust and alliance, and balanced power-sharing, with a respective balanced relevance and consideration of the different expertise of the stakeholders, brings about an exercise of collective agency [91]. Even with this, as De Man and Duysters (2005) point out, alliances must be considered because disparities in corporate culture, operational procedures, and knowledge bases may make it difficult for information to be transferred smoothly for innovation. To limit this drift, innovation should be generated in an open system that can help increase collaboration, optimize resources, and avoid duplicating actions. Furthermore, communication of the strategies to co-create innovation should be primarily aimed at sharing common knowledge about the mutual benefits of collaboration for innovation. Still, users' feedback appears to be a crucial element for driving innovation and contributing to the sustainable development of all the integrated innovation efforts. They are a pillar for improving and maintaining stakeholder support in the medium and long run. Correspondingly, this framework sheds light on the agency's importance in developing innovation for guaranteeing food security. Following the authors of reference [92], 'agency' here refers to 'the capacity of individuals and groups to exercise a degree of control over their circumstances and to provide meaningful input into governance processes, [...] the ability to not only exercise voice and make decisions, but also to act upon them to improve one's own and their community's well-being' [93] (pp. 2–4). Therefore, agency is a fundamental aspect of facing and reducing inequities in co-constructing and accessing innovation within food systems, including power imbalances among actors within those structures and interaction spaces [93,94].

5. Conclusions

This article reviewed the relationships between climate change, food systems, and food security. Climate change produces effects and costs on society and the environment and conditions the possibilities of life and development for present and future generations. However, climate change impacts the world population differently, affecting more vulnerable groups or areas in particular, many of them also characterized by food scarcity problems or periods of frequent famines.

On the other hand, food systems are increasingly sensitive to climate change since they affect levels of agricultural productivity, undermine the logistics of food supply chains and, in some specific cases, displace communities. Furthermore, food systems are responsible for more than a third of the global GHG emissions that cause climate change. This bidirectional relationship places agrifood systems at the center of the attention of environmental activists, researchers, and policymakers, as both a contributor to global warming and a crucial sector for triggering adaptive solutions to climate change. In this sense, food systems are a considerable contributor to climate change. However, climate change impacts food systems unpredictably, leading to food insecurity through adverse impacts on the four dimensions of food security.

Considering this situation, climate change adaptation plans are urgent. They include flood and climate protection strategies, water sustainability, waste management and recycling, climate-smart agriculture, and analytical climate conditions innovation equipment on agricultural processes and activities. Food innovation technologies are seen as a desirable potential solution, among all these alternatives, for facing climate change. However, food systems are intrinsically multiscale, multilevel, and multidimensional. Therefore, the promotion of mitigation and adaptation measures through FITs should also recognize these multiscale and multilevel interactions. In this sense, FITs must be conceived of as means of changing the food system organization and technologies at different scales and levels, either as a response to changes in the spheres connected with it (e.g., ecosystems, socioeconomic systems, etc.) or as a pre-emptive action to influence all these environments. At the same time, food systems are part of global value chains, and climate change is likewise a global problem; thus, FITs should be considered as an integral component of international frameworks, such as the SDG's framework, to facilitate their promotion and dissemination among countries unable to develop them. In this sense, addressing the climate crisis and its adverse impacts on food security through the activation and promotion of innovation needs reliable information and intervention in many different but interconnected fields, such as institutional design, novel partnerships, finance, international cooperation, and philanthropy.

Based on the above, future research might focus on: developing innovative technologies for climate-resilient agriculture; assessing the effectiveness of climate change adaptation strategies in the agricultural sector and, thus, in food security; analyzing the role of institutions, financial mechanisms, international cooperation, and governance in climate change adaptation and food security; understanding the socio-economic and cultural implications of climate change on food security; and quantifying the potential trade-offs and synergies between climate change, food systems, and food security.

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