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Building self-sustainable basic food systems: role of bioactive components and beyond in science and innovation

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Abstract

The world is actively seeking for ways to establish a global food system that demonstrates sustainability in the realms of food security, food safety, and nutrition security. Reflecting on the profound impacts of the COVID-19 pandemic, ongoing war in Ukraine, and accelerated climate crisis with extreme weather events, there arises an urgent necessity for reevaluating the current approach in building sustainable food systems. This contribution considers opportunities and limitations in moving towards more self-sustainable food systems, particularly for basic foods. It also emphasizes the need for caution when contemplating the pursuit of this endeavor and discusses key issues pertaining to basic foods, deforestation, renewable energies, workforce, supply chains, and the environment. Lastly, the roles of science and innovation within the framework of national self-sustaining basic foods systems are elucidated, including opportunities in optimizing the utilization of food bioactive components. It is anticipated that the framework can serve as a tool to foster the development of comprehensive policies that suits the particular needs and development stage of each country. These policies, in turn, will advance the implementation of technologies, promote culture cultivation, and facilitate education and training, all geared towards achieving the goals of a more resilient and sustainable food system.

Keywords: Food systems; Self-sustainable; Basic foods; Role of science and innovation; Bioactive components.

1. Introduction

The latest status of the world's food security and nutrition security have been reported by Food and Agricultural Organization (FAO, 2022), Food Security Information Network and Global Network against Food Crises (2023), Economist Impact (2022), and von Grebmer et al. (2022). Based on open data accessed through FAOSTAT[1], in 2022, a total of 900.1 million people were severely food insecure[2], with the vast majority living in Asia (456.9 million, 51%) and Africa (341.8 million, 38%) continents. At the regional level, the majority of people experiencing severe food insecurity were living in Southern Asia (389.2 million, 43%), Eastern Africa (130.9 million, 14.5%), Western Africa (94.4 million, 10%), Middle Africa (76.7 million, 8.5%), and South America (55.4 million, 6%). At the country level, in 2020–2022, the most severe food insecurity cases were reported in Nigeria (45.4 million), Democratic Republic of the Congo (39 million), Pakistan (29.9 million), Ethiopia (25.3 million), Brazil (21.1 million), Bangladesh (18.7 million), and Tanzania (16.7 million).

Also based on open data accessed through FAOSTAT, in 2022, a total of 735.1 million people were undernourished[3], with the vast majority living in Asia (401.6 million, 55%) and Africa (281.6 million, 38%) continents. At the regional level, the majority of undernourished people were living in Southern Asia (313.6 million, 43%), Eastern Africa (134.6 million, 18%), Western Africa (62.8 million, 8.5%), Middle Africa (57 million, 8%), and South America (26.8 million, 4%). At the country level, in 2020–2022, the most undernourished cases were reported in India (233.9 million), Pakistan (42.8 million), Nigeria (34 million), Democratic Republic of the Congo (33.8 million), Ethiopia (26.4 million), and Bangladesh (18.9 million). Specifically in 2022 for children under 5 years, 45 million were affected due to wasting[4], 148.1 million were estimated to be stunted[5], and 37 million were estimated to be overweight[6].

As mentioned in the preceding reports, primarily three significant developments have regressed all the progress made in combating global hunger to return to the initial state in 2015, which are the COVID-19 pandemic, the ongoing war in Ukraine, and the accelerated climate crisis with extreme weather events. The war represents a dual-faceted issue, with the reduced crop production and trade of agricultural products from Ukraine, and the economic sanctions on Russia and Belarus.

To get the battle against global hunger back on track involves concentrating on regions with substantial populations that are severely food insecure and undernourished, as previously identified, either at the regional or country level. This endeavor needs to be a collective priority by all, involving all stakeholders, but particularly engaging countries capable of promptly offering technical, technological, and/or financial assistance to accelerate the achievement of food systems sustainability in specified regions and/or countries. In addition to supplying food and other essentials and ensuring their safe and reliable distribution, the support should also be channeled towards enhancing the capabilities of the targeted regions and/or countries to optimize the utilization and long-term benefit of their natural resources through the establishment of manufacturing industries that can provide added value.

It is proposed here, that countries initiate a shift towards achieving food security, food safety, and nutrition security through the establishment of self-sustaining basic foods systems. This will need a focus on better understanding the context of self-sustainable basic foods systems and its determinants. There are several challenges that countries need to anticipate and address prior to embarking on this endeavor. A working framework of science and innovation areas is emphasized, that countries should focus on for each subsystem within, as well as throughout, a self-sustainable basic foods system, and consider its vulnerability to climate change related shocks.

2. Sustainable food system framework

The food system is a very complex entity, involving a wide range of contributors and materials that interchange in a vast variety of forms and levels. Ensuring the sustainability of the system adds to the complexity of the desired system outcome, often requiring more contributors and materials, each with their own distinct interactions. Over the years, numerous scholars have endeavored to introduce frameworks for sustainable food systems, often in the form of diagrams aimed at providing a holistic, yet as simplified as possible, understanding of the system. Notable examples include the works of von Braun et al. (2021) and Neufeld et al. (2021). Each of these proposed frameworks employs a unique combination of scope, approach, and components set.

In the context of this contribution, a particular combination of scope, approach, and set of components is needed; distinct from any of the existing frameworks. The requisite scope should encompass categories of food related issues, as well as areas of food and feed production. Meanwhile, the approach should mainly focus on the core food system with an emphasis on the most common understanding of flow from production to consumption. Based on the chosen scope and approach, the set of components can then be identified, both subsystems and flow of food and feed. In this flow, preserving the stability and functionality of nutrients and bioactive components in food and feed should be guaranteed in order to maximize their intake and health benefits.

2.1. Scope

In the most recent understanding of sustainable food systems, sustainability can be established through three main categories of food related issues, which are food security, food safety, and nutrition security. A sustainable food system should promote the attainment of overall well-being, prevent diseases, and treat malnutrition. Many organizations and scholars have offered a variety of definitions for each category, such as the Food and Agriculture Organization (FAO, 2002), United States Department of Agriculture (USDA, n.d.), Oyarzabal and VanRenterghem (2020), Hanning et al. (2012), and Ingram (2020). Occasionally, the definitions overlap each other, leading to some confusion for the general public. In an effort to elucidate this issue, this contribution has highlighted the fundamental distinctions within each category, as shown in Figure 1.

To provide better understanding on the disparities, as well as the interconnectivity, among food security, food safety, and nutrition security, consider the following illustration. Instances of prevailing hunger issues underscore the fact that food is not always readily available, accessible, and properly utilized by all people, consequently resulting in the condition of being food insecure. Incidents of food poisoning and food borne diseases indicate that there are safety issues with the handling, preparation, or storage of our food throughout the supply chain. Irrespective of the impeccable micro and macro composition of foods, their value diminishes if they are unsafe. Finally, enduring malnutrition challenges, encompassing both under- and over-nutrition, serve as indicators that even when foods are readily available, accessible, and adequately utilized, they might invariably contain sufficient or appropriate macro- and micro-nutrients, as well as bioactive compounds.

The scope also extends to the comprehension of key factors that support food security, food safety, and nutrition security. These major supporting factors encompass environmental sustainability, energy sustainability, workforce sustainability, sustainability in research and development, sustainability in education and training, the sustainable integration of advanced technologies, sustainable and secure supply chains, secure and sustainable financial and trading systems, and sustainable supporting policies. Figure 2. Illustrates the comprehensive supporting system.

Another scope that needs to be established is the areas of food and feed production. Many people, including some scholars, still tend to focus heavily on land-based food and feed production, such as farms and forests. Yet, food and feed production can also be aqua-based, both man-made and natural, yielding a rich variety of fisheries, plants, and minerals. Leape and co-workers (2021) have suggested the need to strengthen efforts in aqua-based food and feed production. Due to the unique nature of production management, this contribution will acknowledge the separation of freshwater production from saltwa-

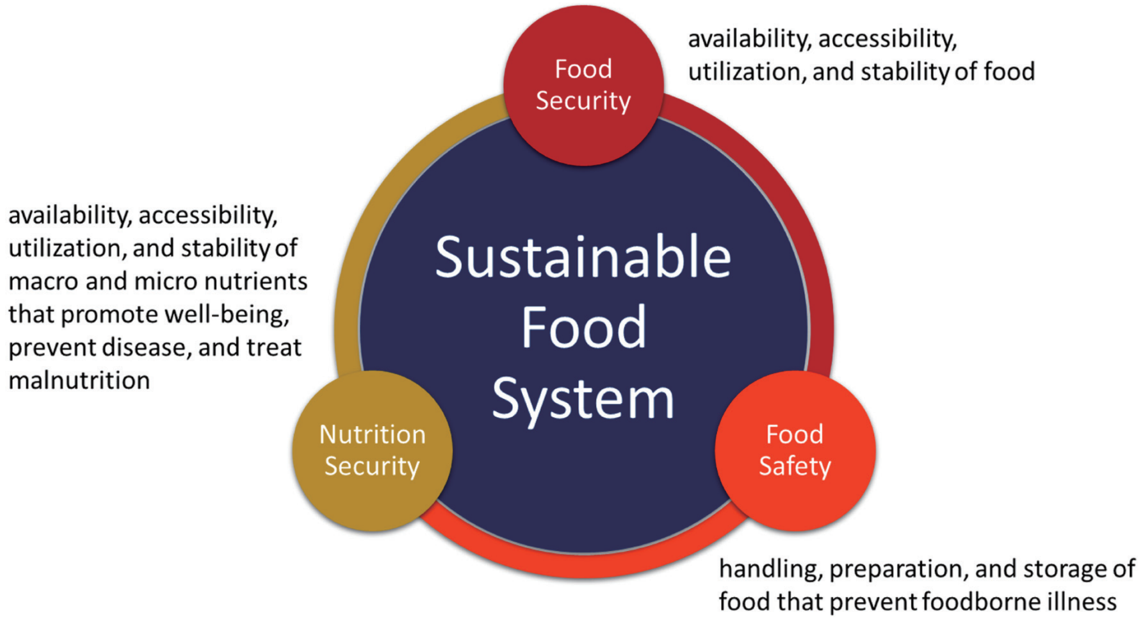

Figure 1. Fundamental distinctions among food security, food safety, and nutrition security.

ter and brackish water. Hence, the area of food and feed production within the scope of the sustainable food system framework should cover land, freshwater, as well as saltwater and brackish water.

2.2. Approach and Components

In reality, there are many contributors to the food system. Some are heavily involved and considered essential due to their specialty in food production and consumption, such as farmers, manufacturing factories, markets, and consumers. Beyond that, there are contributors that more heavily involved and considered essential outside the food system across sectors, such as energy suppliers, machinery producers, policy makers, health providers, financial supporters, educators, and scientists. For the purpose of this contribution, the proposed sustainable food system will mainly focus on the core food system.

In its most common understood form, which involves the flow from production to consumption (sometimes referred to as the "food chain"), the core food system comprises components related to food production, food consumption, and supply chains. Considering that the scope also covers feed, the food production component will need to expand to include both food and feed production.

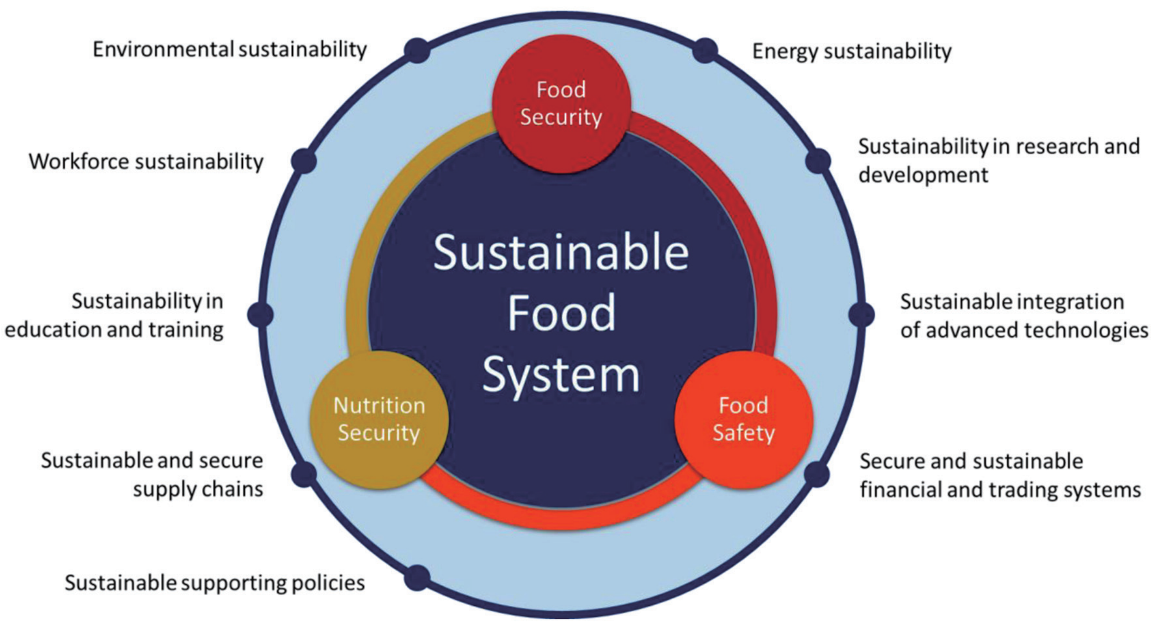

Figure 2. Major supporting factors for sustaining food security, food safety, and nutrition security of food systems.

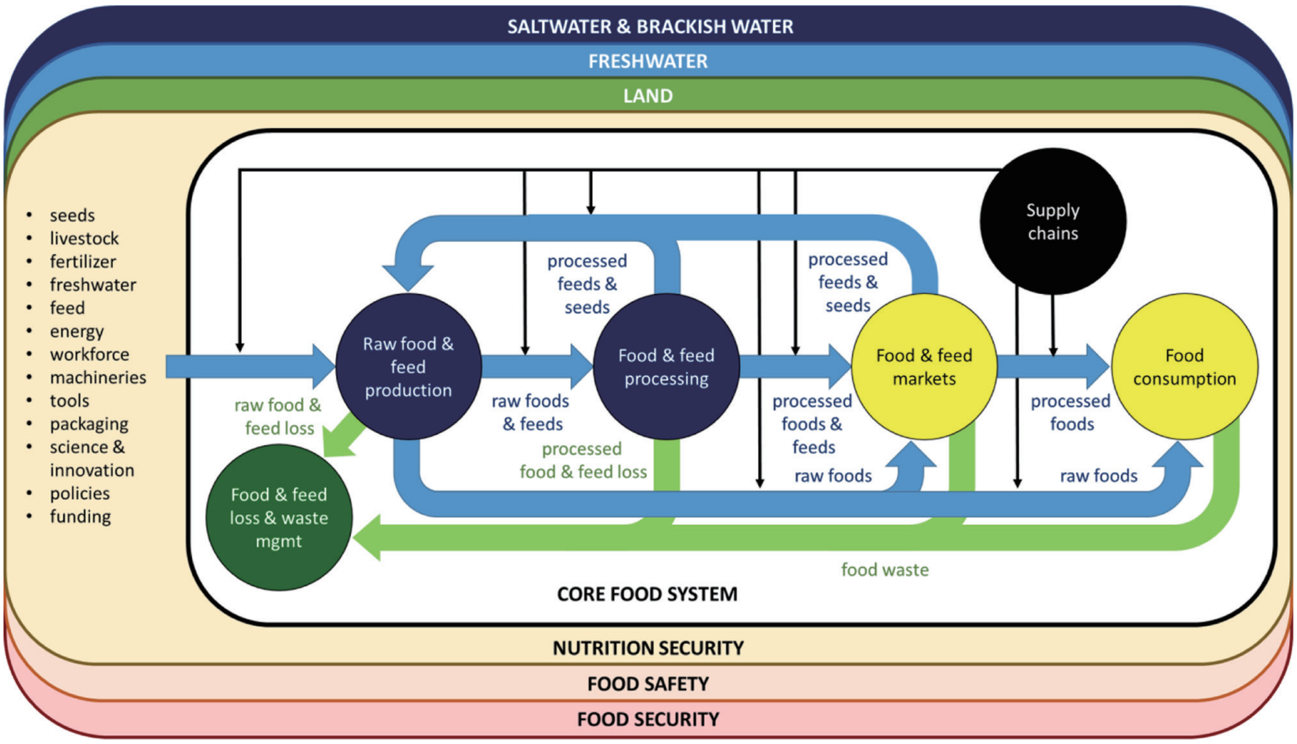

Figure 3. The proposed sustainable food system framework.

Food and feed production can be viewed as a single integrated system or further dissected into two systems: (1) raw food and feed production (e.g. harvesting, netting, etc.) and (2) food and feed processing (e.g. handling, packaging, etc.). The latter option aligns more closely with the purpose of this contribution.

For a more comprehensive understanding of the food consumption component, it is advisable to distinguish between food market and the actual consumption process. This differentiation will also facilitate the tracking of feed flow within the core food system. Consequently, the food consumption component should encompass both the food and feed market, as well as food consumption itself. Meanwhile, despite the supply chains remain as a unified component, there is a necessity to delineate each supply chain within the food system to enhance clarity and comprehension.

The final element within the core food system pertains to the management of food and feed loss and waste. This relates more to the context of sustainability, as it has been advocated by numerous organizations and scholars (e.g. FAO, 2019b; United Nations Environment Programme, 2021; Food and Land Use Coalition, 2019; van Zutphen et al., 2021; von Braun et al., 2021; and Zilberman et al., 2019) as a crucial part of the sustainable food system in recent years. Food and feed loss predominantly occurs at the production, post-harvest, and processing stages, while food waste occurs at the subsequent stages. Therefore, based on the aforementioned identified components within the core food system, food and feed loss transpires during raw food and feed production as well as food and feed processing. Meanwhile, food waste emerges at the food and feed markets along with instances of food consumption.

2.3. Proposed sustainable food system framework

As identified in the previous section, the primary components, hereafter referred to as subsystems within the proposed sustainable food system, include (1) raw food and feed production; (2) food and feed processing; (3) food and feed markets; (4) food consumption; (5) supply chains; and (6) food and feed loss and waste management. In addition to delineating each supply chain, this framework will provide insights into the status and flow of food and feed within the system, thereby emphasizing the interactions among the subsystems. Furthermore, potential major contributors from outside the core food system will be acknowledged based on their contributions rather than as additional components or subsystems, considering them as inputs to the system. Figure 3. illustrates the proposed sustainable food system framework.

The list of inputs from external sources, as shown in the framework, is largely discretionary and will encompass a spectrum of materials, ranging from the widely recognized, such as seeds, livestock, fertilizer, freshwater, and feed to the less acknowledged, including energy, workforce, machineries, tools, packaging, science and innovation, policies, and funding. The flow of these input varies depending on the specific requirements of a given food system at a particular time. For instance, nascent systems may still rely on seeds, initial livestock, and/or feed, while fully operational systems may have their subsystems autonomously generating the necessary materials, obviating the need for such external input. It is important to note that the list of optional inputs meticulously considers the potential needs of both plants and livestock-based, as well as land-based and aqua-based food systems.

The food production subsystems are represented in blue, while the food consumption subsystems are depicted in yellow. The remaining subsystems, namely the supply chains and the food and feed loss and waste management are distinguished by black and green, respectively. The blue arrows and associated statuses symbolize the material flow along the main food chain from production to consumption. Conversely, the green arrows and their

Table 1. Estimated Fatalities of Notable Pandemics since 1968

Years	Pandemic	Pathogens	Estimated Fatalities
1968–1970	Hong Kong flu	Influenza A/H3N2	0.5 to 2 million
2002–2003	SARS	SARS-CoV	774
2009–2010	Swine flu	Influenza A/H1N1	148,000 to 249,000
2012–ongoing	(MERS)	MERS-CoV	936 (2012–2020)
2019–ongoing	COVID-19	SARS-CoV-2	6,953,743

Data for estimated fatalities in 1968–1970 is from *Pandemics throughout History*, by Piret J and Boivin G, 2021 (doi: 10.3389/fmicb.2020.631736). Data for estimated fatalities in 2002–2003 is from *Summary of Probable SARS Cases with Onset of Illness from 1 November 2002 to 31 July 2003*, by World Health Organization, 2015 (https://www.who.int/publications/m/item/summary-of-probable-sars-cases-with-onset-of-illness-from-1-november-2002-to-31-july-2003). Data for estimated fatalities in 2009–2010 are from *Global Mortality Estimates for the 2009 Influenza Pandemic from the GLaMOR Project: A Modeling Study*, by Imonsen, L., Spreeuwenberg, P., Lustig, R., Taylor, R. J., Fleming, D. M., Kroneman, M., et al., 2013 (doi: 10.1371/journal.pmed.1001558). Data for estimated fatalities in 2012–ongoing is from *MERS Situation Update, May 2023*, by World Health Organization, 2020 (http://www.emro.who.int/ health-topics/mers-cov/mers-outbreaks.html). Data for estimated fatalities in 2019-ongoing is from *WHO Coronavirus Disease (COVID-19) Dashboard*, by World Health Organization, 2023 (https://covid19.who.int/).

respective statuses represent the particular flow directed towards the food and feed loss and waste management subsystem. These statuses offer insights into the condition of the flowing material, encompassing aspects such as food/feed, raw/processed, and loss/waste. Lastly, the black arrows denote the location of various supply chains within the main food chain. Interestingly, when observing the flow of material throughout the proposed system, several cyclical flows become apparent. These cycles occur both within the food production subsystems and between the food production and food consumption subsystems, underscoring the need for partial self-sustainability within the core food system itself.

3. Movement towards self-sustainable basic food systems

As previously discussed in this contribution, challenges continue to exist in establishing sustainable food systems across the world. Nonetheless, these challenges have witnessed a notable escalation recently, primarily due to the compounding effects of the COVID-19 pandemic, the ongoing war in Ukraine, and the accelerated climate crisis with extreme weather events. According to Economist Impact (2022), the Global Food Security Index (GFSI), in particular the affordability pillar, has fallen by four percent from 71.9 to 69 between 2019 and 2022, mostly due to the impact of the pandemic and war on the rising costs for food.

Driven by the aforementioned recent significant challenges, this contribution will highlight several key facts to better understand the negative impact of the pandemic, as well as armed conflicts and economic sanctions, on the establishment of sustainable food systems across the world. In addition to food security, when available, facts presented will also cover issues pertaining to food safety and nutrition security, including adequate intake of macro- and micro-nutrients as well as bioactive compounds. Through this understanding, this contribution will then discuss about the emerging need from countries and/or localities to be more self-sustainable in building and fortifying their food systems, in particular pertaining to their basic foods.

3.1. Pandemic

The COVID-19 pandemic was a major shock to the world, as the last reported pandemic with, at least, 1 million deaths worldwide happened more than half a century prior during the Hong Kong Flu in 1968–1969 (Saunders-Hastings and Krewski, 2016, p. 2). Ever since, only three other pandemics had emerge before COVID-19, which were Severe Acute Respiratory Syndrome (SARS), Swine flu, and Middle East Respiratory Syndrome (MERS) (Piret and Boivin, 2021). Fortunately, the three aforementioned pandemics did not have a devastating impact on humanity with relatively low estimated fatalities, hence limiting its impact on the global food system. The severity of each pandemic since 1968 based on estimated fatalities is summarized in Table 1.

Pandemics have the potential to threaten food systems across the key components of its sustainability, namely food security, food safety, and nutrition security. The COVID-19 pandemic, in particular, severely impacted the aforementioned components. In terms of food security, around 83–150 million people were estimated to fall into extreme poverty in 2020 (Klassen and Murphy, 2020; Food and Agriculture Organization, 2020b; Hertel et al., 2021). Global, concentrated value chain productions were disrupted, impacting food affordability and availability for many people across the world (Herrero et al., 2021; Neufeld et al., 2021). In terms of food safety, although SARS-CoV-2 has not yet proven to be transmissible via food, it is still possible to be transmissible between people who are in close contact with each other (Tarver, 2020). This indirect unsafety situation is possible to happen along the food system where food or feed is either produced, processed, marketed, or consumed.

Lastly, in terms of nutrition security, it had been reported that lockdowns have disrupted the production, transportation, and sale of nutritious, fresh, and affordable foods; forcing millions of families to rely on nutrient-poor alternatives (Fore et al., 2020). The higher food prices along with the closing of informal markets have been shown to impact on micro-nutrient (including bioactive) intake and nutritional status of the poor (Neufeld et al. 2021). As a result, it is estimated that there will be an additional 9.3 million children wasted (low weight for height) and 2.6 million children stunted (low height for age) by 2022 (Osendarp et al., 2020). Despite all the aforementioned negative impact, it was also reported that, inversely, many of local value chains have actually seen increases in production and market shares (Herrero et al., 2021; Diao et al., 2021). Based on the discussed impact of COVID-19 on the food system, the longer-term issues highlighted by the pandemic, especially pertaining to the length (including cost-efficiency and streamlining) and security (including agility) of supply chains, will have to be addressed to build better resilience against future shocks.

3.2. Armed conflicts and economic sanctions

While still posing a potential future threat, a pandemic on the scale

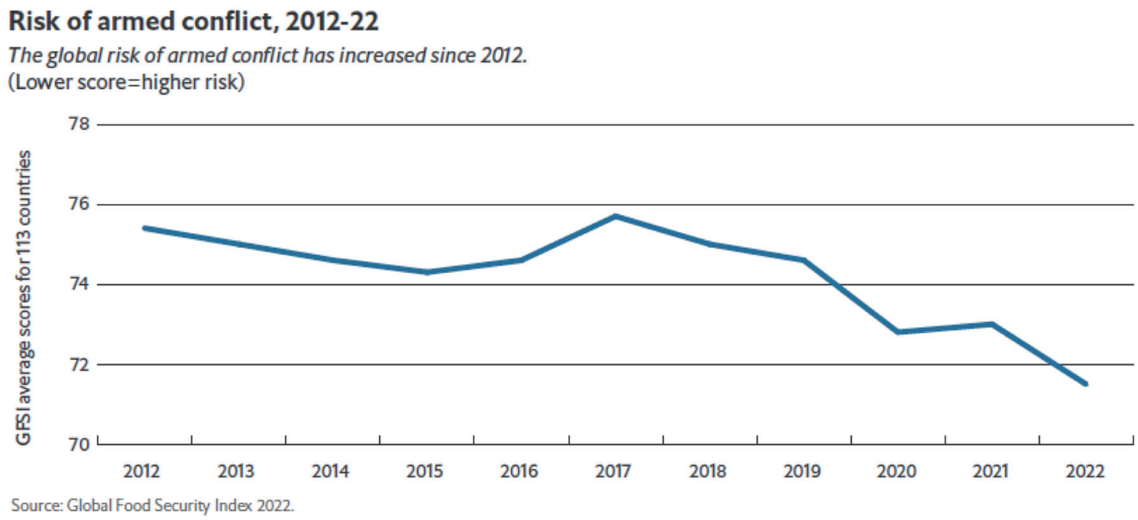

Figure 4. The risk of armed conflict, 2012–2022.

of COVID-19 could be, somewhat, considered an anomaly and there is a hopeful anticipation that it will not reemerge in the near future. On the other hand, armed conflicts have been an ongoing issue, in particular its impact on global food security. Conflict negatively affects almost every aspect of the food system, from production and processing to markets and consumption, as well as the interconnecting supply chains (FAO et al., 2021). Ever since the armed conflicts indicator was first tracked for the GFSI in 2012, there has been an upward trend in its risks toward global food security. In particular from 2019 to 2022, the armed conflicts indicator has fallen (lower score indicates higher risk) by four percent. To make matters worse, of the 25 nations most vulnerable to climate change, 14 are mired in conflict (International Committee of the Red Cross, 2020). The GFSI risk of armed conflict indicator scores between 2012 and 2022 is shown in Figure 4.

As indicated in Figure 4., the risk of armed conflicts emerging across the world is actually continuing to grow. The negative impact becomes even worse when the parties in conflict are major global producers of agrifood products, such as Russia and Ukraine. In terms of wheat production alone, Russia as the third largest produced about 86 million tons in 2020, while Ukraine as the eighth largest produced about 25 million tons (World Population Review, 2023). The combined wheat production of Russia and Ukraine account for nearly 30% of the global wheat trade. In addition, Russia is the second largest fertilizer producer, which supplies almost 10% of the global demand (USDA, 2022). It comes to no surprise that the ongoing war in Ukraine and some indirect effects of economic sanctions on Russia and Belarus are causing a shock on global food security, in particular in, at least, 50 countries (FAO, 2022).

Unfortunately, there are many other armed conflicts still ongoing across the world outside Ukraine and Russia. Many of these countries in conflict have also been the subject of various economic sanctions. In these cases, the majority of people suffering from food insecurity are people living in the conflict and/or economically sanctioned areas. To attain better understanding on the impact of armed conflicts and/or economic sanctions, a summary of number of projected people experiencing food insecurity in Yemen, Congo, Afghanistan, Venezuela, South Sudan, Syria, Zimbabwe, Central Africa, Somalia, Palestine, Lake Chad Basin, and Libya are compiled in Table 2.

The majority of countries/areas reported in Table 2 are within the Africa region, followed by Asia and South America. Yemen, Congo, and Afghanistan have been reported to host the most number of people experiencing food insecurity due to armed conflict and economic sanctions for a total of about 39.5 million people. Meanwhile in Venezuela, economic sanction alone has cause food insecurity for about 9.3 million people. It is also worth noting that in Congo, Afghanistan, Zimbabwe, Somalia, and Palestine, the impact of armed conflict and/or economic sanction has been even more devastating with the occurrence of natural disasters and/or diseases.

3.3. Need for self-sustainable basic food systems

Over the years, several events have forced people to rethink about the sustainability of current food systems that have been heavily influenced and reliant on the global system, highlighted by the previously discussed COVID-19 pandemic, armed conflicts, and economic sanctions. Such events have exposed the vulnerability of the global system and grave consequences for countries over relying on it. As a result, more and more countries are realizing the need to be as self-sustainable as possible and have made this goal a priority. The context of self-sustainable here, however, does not equate to autarky. Instead, self-sustainability is to be considered in relation to food security, food safety, and nutrition security. Regardless of this growing trend, it is important to emphasize that transitioning to a more self-sustainable food system is purely optional and a sovereign right of each country. At the moment, some countries might still prefer to pursue opportunities in obtaining favorable financial gains from trading with other countries.

In an ideal world, every country would be self-sustainable for basic foods which fulfill the recommended daily intake of macro- and micro-nutrients, including bioactive compounds. Based on earlier discussions, completely self-sustainable would indicate that the whole food system, encompassing the aforementioned six subsystems, can maintain sufficient production of each subsystem within itself. In a nutshell, the ultimate self-sustainable food system would operate by its own in a cyclical pattern without requiring input from outside the system, including in the form of material, tools and machineries, manpower, technologies, energy,

Table 2. Number of People Experiencing Food Insecurity in Armed Conflict and/or Economically Sanctioned Areas

Country/Area	Food Insecurity Factors	People Experiencing Food Insecurity
Yemen	armed conflict, economic sanctions	15.9 million (53%) from December 2018 to January 2019
Congo	armed conflict, economic sanctions, natural disaster, disease	13 million in the second half of 2018
Afghanistan	armed conflict, economic sanctions, natural disaster	10.6 million (47%) from November 2018 to February 2019
Venezuela	economic sanctions	9.3 million (32.3%) in 2019
South Sudan	armed conflict, economic sanctions	6 million at the peak of the 2018 lean season and 5 million between January and March 2019
Syria	armed conflict, economic sanctions	5.5 million in August 2018
Zimbabwe	economic sanctions, natural disaster	3.58 million from October-December 2019
Central Africa	armed conflict, economic sanctions	1.9 million in August 2018
Somalia	armed conflict, economic sanctions, natural disaster	1.8 million in July 2018
Palestine	armed conflict, disease	1.78 million in 2020
Lake Chad Basin	armed conflict	1.7 million in October–December 2018
Libya	armed conflict	222,620 in 2022

Data for Yemen, Congo, Afghanistan, South Sudan, Syria, Central Africa, Somalia, and Lake Chad Basin are from *Monitoring Food Security in Countries with Conflict Situations: A Joint FAO/WFP Update for the United Nations Security Council*, by FAO, 2019a (https://www.fao.org/3/ca3113en/CA3113EN.pdf). Data for Venezuela is from *The Economic Determinants of Venezuela's Hunger Crisis*, by Rodriguez, F., 2022 (https://mpra.ub.uni-muenchen.de/113669/1/ Economic%20determinants%20of%20Venezuela%27s%20hunger%20crisis.pdf). Data for Zimbabwe is from *Zimbabwe: Food Insecurity Information Bulletin*, by International Federation of Red Cross and Red Crescent Societies, 2019 (https://reliefweb.int/attachments/ed205896-2f6b-35ce-84cc-ceb769474e5e/IB_Zimbabwe_Food_Insecurity.pdf). Data for Palestine is from *Socio-economic and Food Security Survey 2020: State of Palestine*, by Palestine Economic Policy Research Institute, 2020 (https://fscluster.org/sites/default/files/documents/socio-economic_and_food_security_survey_sefsec-2020_full_report.pdf). Data for Libya is from *Libya Annual Country Report 2022: Country Strategic Plan 2019–2023*, by World Food Program, 2022 (https://reliefweb.int/attachments/6b63c3e5-640a-4636-8486-19221b167a58/libyaWFP-0000147971.pdf).

and finances. The transition period for countries to fully implement a self-sustainable food system could, realistically, take quite a long time. For some countries, this goal might not even seem fully achievable, at the moment. This challenge should be seen as an opportunity for individuals involved in science and innovation to seek for future enabling alternative solutions.

When put into this reality, it becomes obvious that establishing a self-sustainable system for all types of foods preferred by the locals is an insurmountable task for any country, both now and in the near future, given the limitations in natural, technological, manufacturing capacity, and/or financial resources of each country. Hence, to make the goal more feasible, this contribution suggests for interested countries to start off with the self-sustainability of their basic foods.

4. Challenges in moving to self-sustainable basic food systems

Developing sustainable food systems is considered a major challenge by many countries across the world. A decision to start moving toward a self-sustainable one, albeit even solely for the basic foods of a country, could prove to be even more challenging as the complexity increases exponentially. Despite the alarming experiences discussed earlier in regards to the COVID-19 pandemic and the ongoing war in Ukraine, not all countries have the resources to complete, or even start, the move. Even for countries that are currently capable of making the transition, they will need to be cautious against moving too far forward toward self-sustainability in food systems, because it comes at a cost of trading opportunities. There is an optimal point for each country between self-sustainability and complete openness of food systems. Regardless, a movement toward more independence (not isolation) from the global food system should be taken into consideration. This contribution will attempt to offer several points of consideration for countries that are pondering such a move based on seven foreseeable issues, which include (1) finding balance between a production-push approach and a consumption-pull approach when determining basic foods, (2) assessing the consequences of land use change and related deforestation, (3) transitioning to renewable energies, (4) maintaining an adequate and competent workforce, (5) enhancing the security and shortening the length of supply chains, and (6) protecting the environment.

4.1. Finding Balance between a Production-Push Approach and a Consumption-Pull Approach when Determining Basic Foods

Basic foods for each country might differ, depending on a number of a factors, including local weather conditions, potential production capacity of local plants and livestock, as well as local cultural and religious diets. Basic foods might also differ among localities within the country that, geographically and historically, have access to different natural food resources and have accepted the unique foods as part of its cultural identity. It is important to note that local cultural and religious considerations, for some countries, are as essential as the nutrient and bioactive composition, particularly in countries that are natively culturally diverse and/or practice strong religious values.

In determining the basic foods of a country, it is important strike a balance between production-push and consumption-pull. Production-push dominance occurs when bulk acquisitions of raw foods at favorable costs by food producers drive global food processing subsystems to initiate innovations that diversify the products, manufacture new nutritious and healthy products, introduce

Table 3. Strength and Issues of Production-push Dominance and Consumption-pull Dominance

Dominant Factor	Strengths	Issues
Production-push	Global coverage; Introducing new diversified ingredients; More attractive; More convenient; More accessible; More affordable; Ready to combat hunger, under-nutrition, fortification.	Healthy diets offered could possibly change the local diets; Over reliant on imports, hence more susceptible to shocks and disruptions; Prone to impulse purchasing, potentially leading to over-nutrition or food waste.
Consumption-pull	Local culinary and practices provide healthy diets and richness of available menu; New potential like halal food markets may have potential consumption-pull driven activities.	Lack of awareness on consumers understanding about healthy diets and balanced nutrition, proper use of food ingredients, and safety; Lack of information on consumer behaviors, local and indigenous culture, food habits, and traditional knowledge; Limited scientific development at consumers perspective end, including innovation for social and institutional building; Lack of innovation and weak driving direction compared with production-push.

biodiversity of plant- and animal- based ingredients and commodities, develop convenient food products that have better taste and are attractive to consumers with the bottom-line goal of maximizing profits from sales. These products are massively pushed into global markets using persuasive marketing and pricing strategies that effectively influence consumer behavior in terms of purchasing and consumption patterns. In this scenario, food producers will dictate the type of foods to be acquired and consumed by consumers, even in countries where the products are foreign.

Conversely, consumption-pull dominance occurs when consumers will only acquire and consume foods that fulfill their physical (i.e. health concerns), social (i.e. cultural identity), spiritual (i.e. religious obligations), and financial (i.e. affordable) well-being. These food products would typically be produced within the specific religious corridors of the consumers using traditional and local indigenous knowledge and cultural wisdom related to basic local foods. They are then acquired in the form of traditional local cuisines and consumed according to the local dietary patterns. Unfortunately, in many countries, nationally recognized traditional wisdom based on local resources remains widely unknown due to a lack of information and various other factors. The food products resulting from this approach are also often still susceptible in terms of cost-effectiveness and mass production capacity, and they frequently lack the persuasive marketing and pricing strategies required to foster consumer loyalty. To gain a better understanding of production-push and consumption-pull, the strengths and issues of each are described in Table 3.

In reality, consumption-pull is currently less dominant than production-push. Despite its commendable attributes such as offering healthy diets, a wide range of menu choices, and tapping into the potential of the halal food market, there persist several significant challenges that demand attention. These challenges encompass a lack of awareness and information, limited advancements in scientific research, and a dearth of innovation. On the other hand, production-push has numerous advantages over consumption-pull, which include global coverage, incorporation of novel ingredients, enhanced visual appearance, greater convenience, improved accessibility and affordability, as well as readiness to combat hunger, under-nutrition, and food fortification. Despite its many strengths, possible changes in local diets, over reliant on imports, and prone to impulse purchasing are a couple of examples of such lingering issues.

Given the situation, countries that intend to move toward a more self-sustainable basic foods system will need to protect and strengthen (1) local production-push of traditional and local culture diets that promote health and are price-friendly using their chosen local basic foods; and (2) local consumption-pull of such products through the use of advanced packaging, storage, and handling technologies, as well as effective marketing and pricing strategies, to improve convenience, attractiveness, and taste. Maintaining balance between production-push and consumption-pull of local food products produced from the chosen basic foods will better ensure its sustainability, leading to a more self-sustainable basic foods system.

4.2. Assessing the consequences of land use change and related deforestation

Given the continually increasing demand for food due to a growing global population, one of the most traditional and direct methods to increase raw food and feed production involves the conversion of land usage – transitioning from forests, swamps, plains, and deserts to agricultural land or land-based aquaculture area. The prolonged and intensified pursuit of this conversion, however, has not consistently resulted in the desired sustainable benefits for humanity. Deforestation is a major contributor to environmental deterioration and the decline of biodiversity, in which 80% of it has been contributed by the global food system through soil erosion, desertification, water scarcity, and diminishing biodiversity (Food and Land Use Coalition, 2019). Since the 1960s, the destruction of over half of the world's tropical forests has had profoundly adverse effects on approximately 1 billion impoverished individuals whose livelihoods depend on these forested areas (Alroy, 2017). This has become an ongoing conundrum in efforts to establish food security as illustrated in Figure 5.

As reported in World Metrological Organization (WMO, 2023), various severe weather continue to emerge as a result of the ongoing climate changes, including heat waves, droughts, wildfires, tropical cyclones, severe storms, heavy rain, flooding, and cold extremes. The report stated that in 2022, heat waves, severe droughts, and wildfires emerged in Asia[7], Europe[8], Africa[9], South America[10], and North America[11]. WMO (2023) continued to report that during 2022, tropical cyclones, severe storms, heavy rain, and flooding emerged in Asia[12], Oceania[13], South America[14], Africa[15], North America[16], Caribbean[17], and Europe[18]. Meanwhile, cases of cold extremes were reported in North America[19], Europe[20], Africa[21], and South America[22]. The majority of those severe weather events had been reported to lead to gross losses of crop and/or livestock, while in some cases the severe weather had also led to human fatalities and population displacement.

According to Lawrence and Vandecar (2015), future agricultural productivity in the tropical regions is at risk from an increase in temperature anomaly[23] caused by deforestation along with its

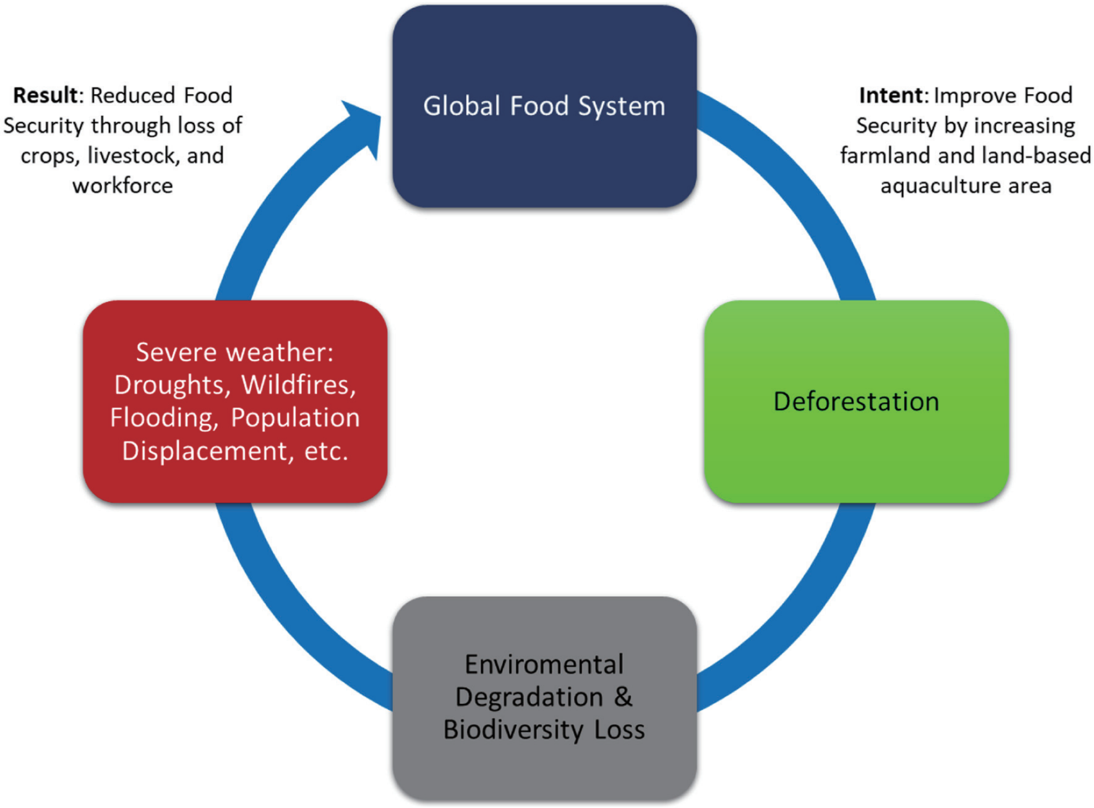

Figure 5. Global food system expansion conundrum.

cascading impact, from severe weather to loss of workforce. Drastic adjustments in our consumption patterns and sustainable land management practices are required to avoid further needs from the global food system for deforestation (Erb et al., 2016; Smith et al., 2020). Reforestation, the restoration of degraded lands, and the expansion of agroforestry efforts must excel worldwide, particularly in the least productive areas, such as deserts, and in countries that are most food insecure due to limited agricultural land. The recent global trend of concern involves a declining ratio between forest expansion and deforestation from 10:15 (0.67) hectares per year in 2000–2010 to 12:22 (0.55) in 2010–2020, including from 7:12 (0.58) in 2010–2015 to 5:10 (0.50) in 2015–2020, needs to urgently be addressed (FAO, 2020a).

This concern should be tackled not only domestically but also in relation to potential trade partners on which the country might continue to depend for imported food products during its transition phase. As many countries strive for self-sustainability, those opting to embark on this journey must take into account cascading impacts of climate changes, in particular ones caused by deforestation. Local trend in severe weather in terms of pattern and impact, along with the short- and medium-term strategies employed by potential trading partners to address this concern, are some issues that a transitioning country should consider when planning for long-term collaboration.

4.3. Transitioning to renewable energies

A consistent supply of energy is essential in modern agriculture throughout the food system − spanning from the raw food and feed production subsystems (e.g. planting, fertilizing, watering, feeding, harvesting, etc.) to food consumption (e.g. storage, preparation, etc.). It also plays an important role in the supply chain subsystems (e.g. storage, transportation, etc.) as well as the food and feed loss and waste management subsystems (e.g. feed conversion, fertilizer conversion, energy conversion, etc.). Energy is primarily required to operate many machineries necessary to improve the capacity and quality of the subsystems within the food system. This is generally driven by increases in demand for quantities (due to growing populations) and quality (due to extended storage time), lack of a sufficient workforce (due to a decrease in occupational interest), and/or better financial gains (due to better costs of operating machineries compared to paying wages and benefits).

With its aforementioned essential role, sustainable supply of energy is one of the key needs in developing sustainable food systems. Developing more self-sustainable energy resources is desirable, especially when moving to more self-sustainable basic food systems. With fossil fuels being evidently not renewable, hence unsustainable, as well as the concerns with nuclear energy, countries and localities need to contribute towards the global development of renewable energy technologies and implement plans to gradually develop national and local renewable energy resources. Indeed, many countries across the world have been engaged in this global effort with an overall increase in generation capacity over the years as shown in Figure 6.

From 2010 to 2022, the Asia Pacific region appears to be the sole geographic area that has shown growth in renewable energy generation across all currently supported resources. Additionally, the Asia Pacific region is the highest renewable energy generator (3,914.03 TWh)[24] led by China (2,670.18 TWh)[25], India (380.87 TWh)[26], and Japan (226.93 TWh)[27]. While hydropower remains

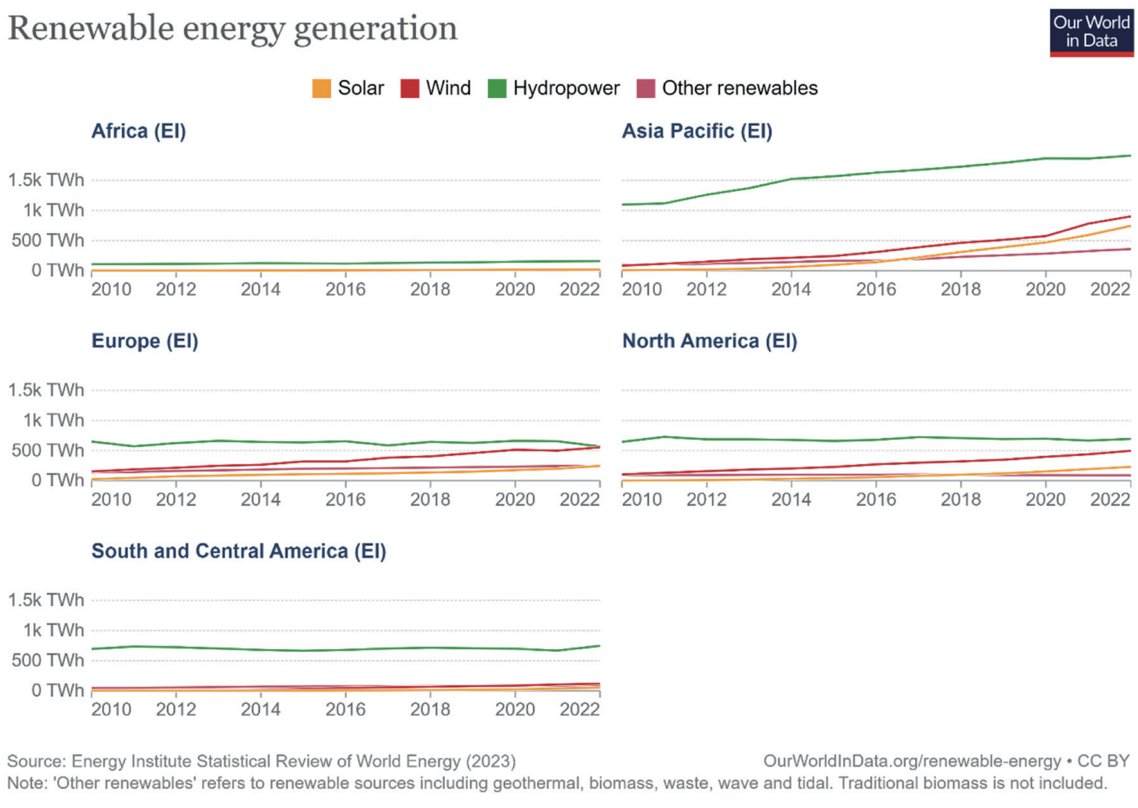

Figure 6. Renewable energy generation per major region (2010–2022).

the top renewable energy generator across the compared regions, only the Asia Pacific region appears to significantly increase its generation by 813.84 TWh (74%)[28]. In fact, the Europe region actually showed a minor drop in hydropower generation by 83.90 TWh (−13%)[29]. Furthermore, wind power appears to be the second most pursued renewable energy generator across the compared regions, followed by solar power. From the comparisons, it is also worth noting that the Africa region might be facing the toughest challenges in developing their renewable energy resources.

Renewable, however, does not necessarily mean that the hydropower, wind power, solar power, and other renewable energy resources are all sustainably reliable, in that their generation can be human-controlled. For instance, wind power and solar power are highly reliant on nature conditions. In addition, the cost of implementing the renewable energy technologies, including recycling energy storages, like solar panels and batteries, are currently still considerably expensive. Another concern is the use of limited land space and massive changes in crop utility to develop biomass energy. Hence, due to these circumstances, it is important that transitioning to renewable energies is pursued in a gradual (incremental decrease in fossil fuels reliance) and diverse (implementing a variety of renewable energy resources) manner, while the renewable energy technologies gain more advancement. Maintaining food security and avoiding any potential social unrest should be prioritized over rapid and drastic transitions.

4.4. Maintaining an adequate and competent workforce

Adequate size and competent workforce throughout the food system is another essential requirement in modern agriculture. With the continual growth of global population size, consequently, there is a rising demand for massive food and feed production. According to Roser (2013), the global agricultural workforce size, however, showed a continual decline from 2010 to 2019, both in terms of number of people from (1.04 billion to 927.92 million) and percentage of total employment (from 33.03 to 26.76%). Despite still hosting the largest number of agricultural workers, the highest decline in number of people is reported in the East Asia and Pacific region, from 419.40 million to 314.92 million. In contradiction, the Africa region has actually shown an increase in number of people from the same period, in particular the eastern and southern parts (from 133.21 million to 162.54 million) and the western and central parts (from 62.04 million to 64.25 million). The number of people and share of workforce employed in agriculture from 2010 to 2019 is depicted in Figures 7 and 8, respectively.

Given that the majority of significant raw food and feed production zones, encompassing both land-based and aqua-based systems, remain situated in rural regions, it is logical to expect that the bulk of the workforce would be residing in close proximity. The projection, however, shows that global urbanization will continue to grow in North America (81.6%), Latin America and the Caribbean (79.9%), Europe (73.9%), and East Asia and Pacific (68%) by 2050 (United Nations [UN], 2018; Baeumler et al., 2021). On the other hand, global rural population will continually decline from 3.4 billion in 2018 to 3.1 billion in 2050 (UN, 2018). This urbanization trend is, perhaps, one of the reasons for the decline in agricultural workforce.

Addressing the necessity of maintaining an adequate agricultural workforce number has primarily been managed by developed

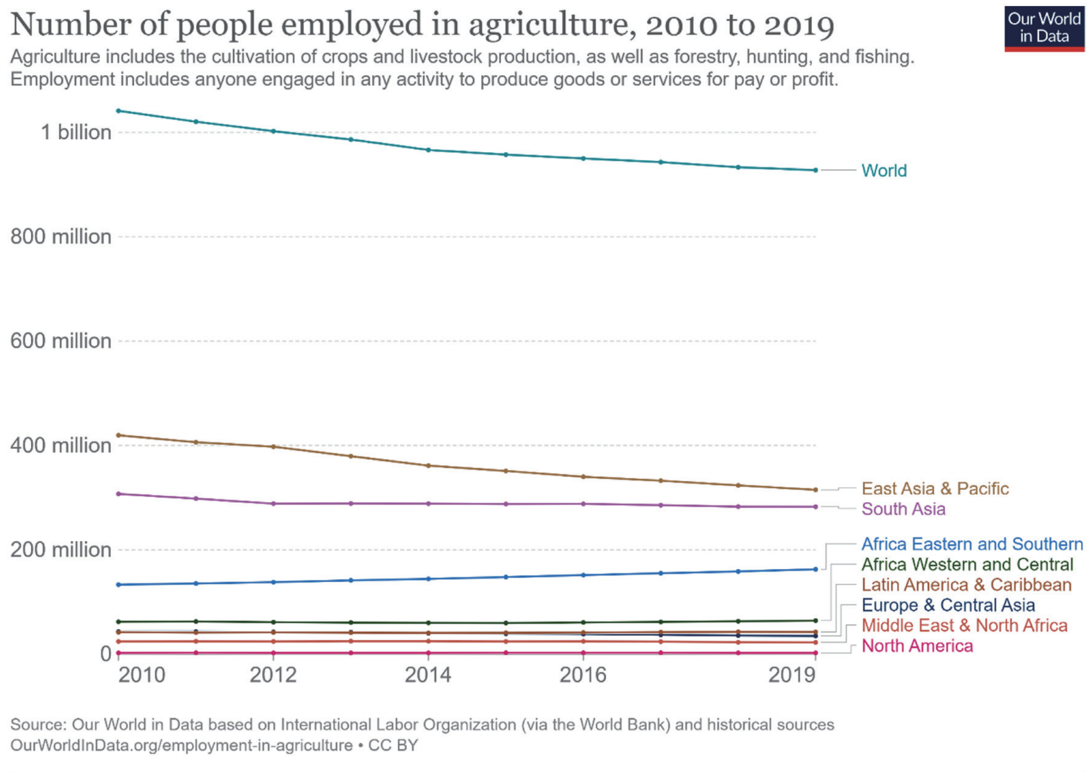

Figure 7. Number of people employed in agriculture from 2010 to 2019.

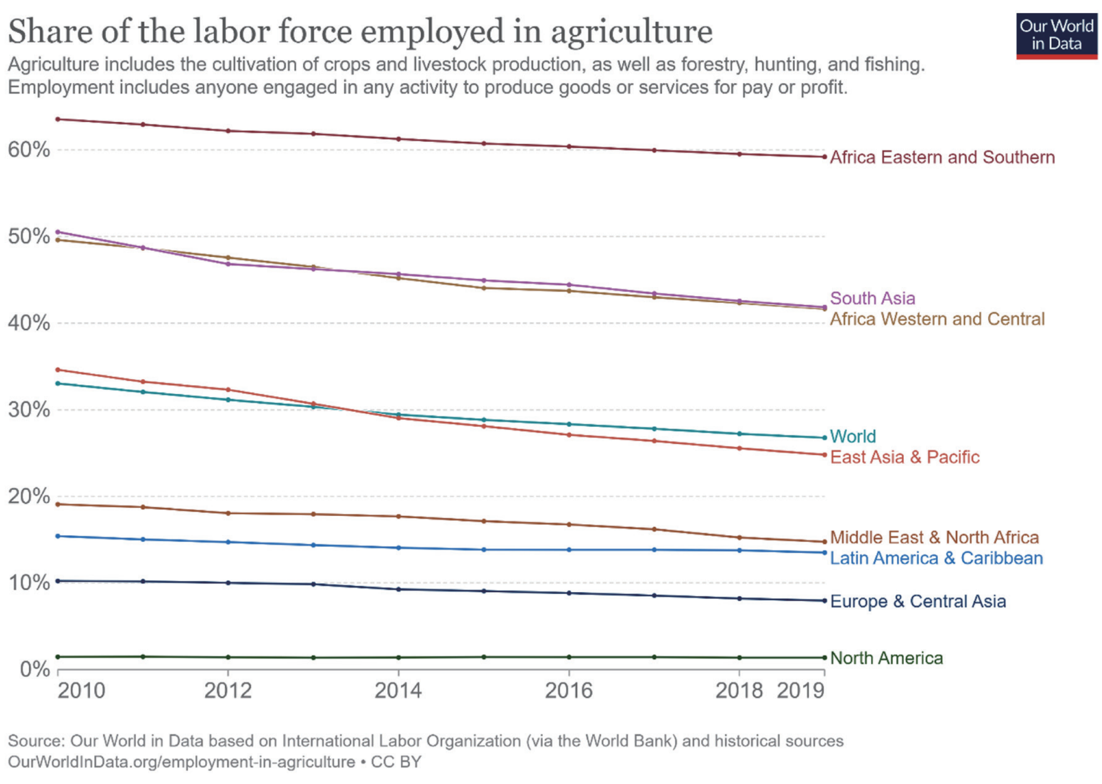

Figure 8. Share of labor force employed in agriculture from 2010 to 2019.

countries through a dual strategy involving immigrant labor from less developed nations and substantial investments in machineries and other advanced technologies. The use of immigrant labor in the short- and medium-term has been beneficial in terms of cost-effectiveness (Guzi et al., 2022). Typically, immigrant labor is inclined to accept lower wages while possessing adequate or even superior skills compared to native labor, owing to the relatively lower income standards in their countries of origin. During this period, immigrant labor and their families generally exhibit a higher tolerance for various social barriers they encounter. As the next generation from the immigrant labor are born, raised, and attain citizenship, demands for equal treatment and opportunities, including fair pay, start to emerge. The capability and willingness of the original native populations, both government and society, to accommodate these demands will determine the long-term viability of this approach.

Although the decision to heavily invest in agricultural machineries and advanced technologies is often driven by the objective of augmenting both quantity and quality of a food system, some countries might be forced to take this approach to simply replace the decline in their agricultural workforce. Regardless of the underlying motives, movement from traditional raw food and feed production to operating and maintaining agricultural machineries and advanced technologies will require significant improvement in competencies of the workforce. This might present a major challenge for seasoned agricultural labor as they would have to go through intensive training to upgrade their skills. In fact, the new requirements might push them to seek for new employment in other sectors, actually causing further decline in the current workforce. Governments will need to proactively strategize and plan in advance to effectively address this potential concern.

A more self-sustainable approach would oblige governments to optimize the potential of their own citizens in meeting national development goals. Instead of risking a potential future social unrest from immigrant labor and their families, governments should build a culture-based social structure within the country that best suits their needs. A proper education and training system will be vital in encouraging early pursuance of future career paths that closely meets the development needs of the country. It will also be needed to support the transition from traditional agricultural production practices to more modern ones, especially in regards to the proper utilization of ongoing advancements in machineries and other technologies.

Proper investment in research and development that support national needs in science and innovation is another important factor in moving toward self-sustainability. Strong patriotic spirit, retirement financial security, and proper social recognition of service are some of the fundamental cultural pillars that will need to be cultivated in building the required social structure. Citizens working in the national food system should have a sense of pride and receive appreciation for serving their country while feeling financially safe about their post-career years. It is quite astonishing that financial inequalities still exist to the extent that "while farmers are the stewards of half of the land on Earth and produce 95% of food, they also comprise 65% of the world's poorest people" (World Economic Forum [WEF], 2022).

4.5. Enhancing the security and shortening the length of supply chains

Lengthy supply chains, both in terms of distance and time, have been considered a problem even before being further magnified through the COVID-19 pandemic and the ongoing war in Ukraine, as many trades had to be transported via less favorable routes and/or means. Insecure supply chains due to armed conflicts and economic sanctions not only impact the countries in dispute, but also countries that have trades with and/or simply use trade routes within or near the countries in dispute. It is apparent that countries seeking to build a sustainable food system would desire shorter and better secured supply chains.

This is more likely to be achieved through supply chains with neighboring countries that share economic and security aspirations and are willing to cooperate symmetrically to reach their common goals of prosperity, peace, and well-being for their people. Hence, despite being established for many years, many regional cooperation have recently pushed for stronger ties; some due to the indirect impact of the armed conflict in Ukraine. For example, the decision of Brazil and Argentina to rejoin the Union of South American Nations in 2023 after a four year hiatus. The accelerated growth of the Shanghai Cooperation Organization is another example with nine member countries and 16 countries either formally engaging as observers or dialogue partners. The locations of the most prominent regional economic cooperation are shown in Figure 9.

As depicted in Figure 9, the most prominent regional economic cooperation on the America continent are the US-Mexico-Canada Agreement (USMCA) in North America and the Union of South American Nations (Union de Naciones Suramericanas, UNASUR) in South America. On the Africa and Europe continent, each have one prominent regional economic cooperation, which are the African Union and European Union, respectively. Meanwhile on the Asia continent, three prominent regional cooperation are thriving, which are the Association of Southeast Asian Nations (ASEAN) in Southeast Asia, the Gulf Cooperation Council (GCC) in Middle East Asia, and the Shanghai Cooperation Organization (SCO) stretching across East Asia (China), South Asia (India and Pakistan), Central Asia (Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan), Middle East Asia (Iran), and Europe (Russia). An illustration on the potential economic strength of each regional economic cooperation mentioned above is shown in Table 4.

From Table 4, despite only on having nine members, SCO is potentially the strongest regional economic cooperation across the four indicators (area, population, GDP-PPP, and manufacturing output). It has the potential to become even stronger in the coming years with many neighboring countries in Central, South, and Middle East Asia showing strong interest in joining in the future. From the remaining regional economic cooperation, perhaps, only UNASUR has the potential for further significant growth, as it once had 12 members when it was first established, as well as its closer cultural ties with the Central America region. Unless ASEAN decides to expand to the Oceania region, the other regional economic cooperation will most likely have to rely on the growth within their current membership to gain further economic strength.

4.6. Protecting the environment

A critical aspect of establishing self-sustaining basic food systems revolves around the preservation of the environment, specifically ensuring the quality of the water, land, and air in which food cultivation and production take place. Land is the foundation of human well-being, providing food, water, and biodiversity. Over 70% of global land is directly impacted by human use. It's vital for climate regulation, with a significant portion dedicated to food, fiber, and energy production. Projected population and income growth, coupled with shifting consumption habits is increasing demand for food, feed, and water. These changes, influenced by land management practices, will impact land use, food security, water availability, greenhouse gas emissions, carbon sequestration potential, and biodiversity.

Climate change and extreme weather pose threats to land eco-

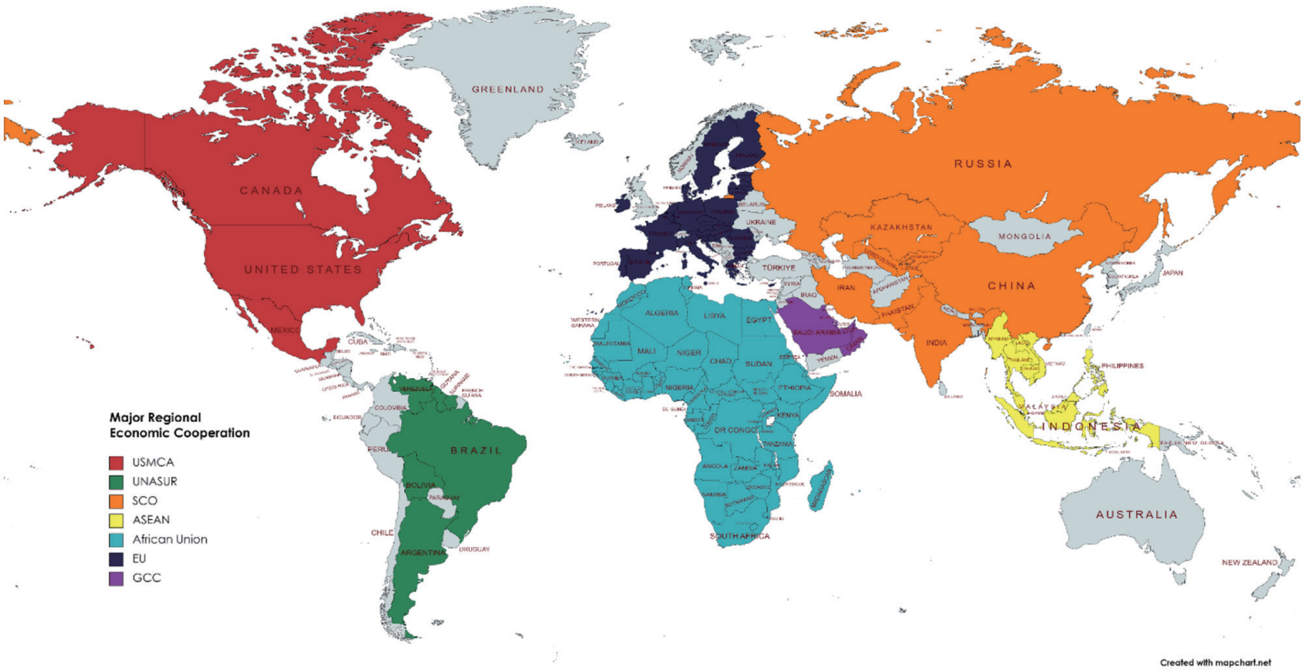

Figure 9. Map of the most prominent regional economic cooperation.

systems and biodiversity. Increases in frequency and intensity of extremes have adversely impacted food security and terrestrial ecosystems, as well as contributed to desertification and land degradation in many regions. Therefore, sustainable land management is essential to mitigate these impacts on ecosystems and societies. Elevations in the global mean surface temperature have profound consequences on various processes, encompassing desertification leading to water scarcity; land degradation involving soil erosion, vegetation loss, wildfire, and permafrost thaw; and food security influencing crop yields and food supply stability. These alterations in processes pose substantial risks to food systems, livelihoods, infrastructure, land value, as well as human and ecosystem well-being. Moreover, shifts in one process, such as wildfires or water scarcity, can exacerbate multiple risks simultaneously. It is important to note that these risks are highly location-specific and exhibit regional variations (Hurlbert et al., 2019).

Table 4. Major Regional Economic Cooperation Potential Economic Strength by Manufacturing Output

Cooperation	Country Members	Area (km^2)	Population	GDP (PPP) (USD trillion)	Manufacturing Output (USD billion)
Shanghai Cooperation Organization (SCO)	9	36,041.93	3,369,305,500	51.68	5,887.37
USA–Mexico–Canada Agreement (USMCA)	3	21,675.64	499,721,584	30.48	2,924.97
European Union (EU)	27	4,574.03	447,956,050	24.30	2,320.66
Association of Southeast Asian Nations (ASEAN)	10	5,219.81	679,445,102	10.32	765.12
Union of South American Nations (UNASUR)	8	16,659.93	387,900,580	7.18	311.03
Gulf Cooperation Council (GCC)	6	3,372.15	58,862,470	3.82	256.31
African Union	55	30,562.97	1,424,583,380	8.28	72.66

Data for SCO country members is from *General Information*, by SCO Secretariat, n.d. (http://eng.sectsco.org/cooperation/20170110/192193.html). Data for USMCA country members is from *United States-Mexico-Canada Agreement*, by International Trade Agreement, n.d. (https://www.trade.gov/usmca). Data for EU country members is from *Country profiles*, by Directorate General for Communication, n.d. (https://european-union.europa.eu/principles-countries-history/country-profiles_en). Data for ASEAN country members is from *ASEAN Member States*, by ASEAN Secretariat, n.d. (https://asean.org/member-states/). Data for UNASUR country members is from *Brazil to rejoin Union of South American Nations – UNASUR*, by Verdello, A., April 10, 2023 (https://agenciabrasil.ebc.com.br/en/justica/noticia/2023-04/brazil-formalizes-return-unasur). Data for GCC country members is from *Member States*, by Secretariat General, n.d. (https://www.gcc-sg.org/en-us/AboutGCC/MemberStates/Pages/Home.aspx). Data for African Union country members is from *Member States*, by African Union Commission, n.d. (https://au.int/en/member_states/countryprofiles2). Data for area are calculated based on data 2020 from *Surface area (sq. km)*, by World Bank, n.d. (https://data.worldbank.org/indicator/AG.SRF.TOTL.K2); data for Sahrawi Republic (Africa Union) is unavailable. Data for population are calculated based on data 2022 from *Population, total*, by World Bank, n.d. (https://data.worldbank.org/indicator/SP.POP.TOTL); data for Sahrawi Republic (Africa Union) is unavailable. Data for GDP (PPP) are calculated based on latest available data (2020–2022) from *GDP, PPP (current international $)*, by World Bank, n.d. (https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.CD); data for Sahrawi Republic (Africa Union) is unavailable; data for Eritrea (Africa Union) and South Sudan (Africa Union) are prior to 2020. Data for manufacturing output are calculated based on latest available data (2018–2021) from *Manufacturing, value added (current UD$)*, by World Bank, n.d. (https://data.worldbank.org/indicator/NV.IND.MANF.CD); data for Bulgaria (EU), Comoros (Africa Union), Malawi (Africa Union), and Sahrawi Republic (Africa Union) are unavailable; data for Burundi (Africa Union), Eritrea (Africa Union), Liberia (Africa Union), Somalia (Africa Union), South Sudan (Africa Union), Sudan (Africa Union) are prior to 2018.

Effective waste management and reduction are essential throughout all phases of aquaculture, agriculture, food production, supply chains, and consumption. The practice of composting biodegradable materials, including agricultural waste and house food scrap, plays a pivotal role in recycling efforts and the minimization of organic waste. Each country has different ways to handle food packaging materials. Plastic is extensively used as food packaging material to safeguard against quality deterioration and microbial contamination. This, in turn, extends the shelf life of food products, reducing food waste, enhancing food security, and ensuring both food safety and nutrition security. However, plastic is non-biodegradable material and the world presently faces significant challenges associated with plastic waste. The most critical concern revolves around microplastic pollution, which has now infiltrated the food chain. Remarkably, plastic waste is not confined to terrestrial environments; but it also contaminates rivers and oceans, exacerbating the problem. The management of plastic waste varies from one country to another, underscoring the urgent need for a global initiative to identify alternatives to plastic packaging and to intensify research aimed at combatting our ongoing plastic pollution crisis.

5. Strategies to build self-sustainable basic food systems through science and innovation

The role of science and innovation in shaping food systems varies significantly among countries and localities, primarily due to their unique circumstances. These circumstances encompass their developmental stage, the nature of their staple foods, financial resources, workforce capabilities, as well as the influence of their policies and regulations. This contribution aims to provide insights into specific focal points and most importantly, seeks to comprehend the extent and diversity of science and innovation needed to establish self-sustainable basic food systems.

When it comes to broader sustainable food systems, the fundamental approach remains compatible, although there may be variations in the specific areas of emphasis. For example, achieving self-sustainability may require reduced reliance on the global food system, in particular concerning lengthy and/or volatile supply chains. Conversely, a state of basic sustainability can be attained even when maintaining a substantial dependence on access to and affordability of the global food system.

5.1. Mapping focus areas related to the core food systems

As mentioned earlier, the core food system comprises six subsystems, which are (1) raw food and feed production; (2) food and feed processing; (3) food and feed markets; (4) food consumption; (5) supply chains; and (6) food and feed loss and waste management. The integrated system should be capable of achieving food security, food safety, and nutrition security by optimizing the potential of both land-based and aqua-based production. To accomplish this, science and innovation play a critical role in developing essential systems (e.g. standards, procedures, etc.), advancing technologies (e.g. tools, machineries, etc.), maintaining a skilled workforce (e.g. education, training, social structure, etc.), and fostering a supportive cultural environment (e.g. promoting local foods, culture resilience, etc.). This implies the necessity of adopting a multidisciplinary approach to establish self-sustainable basic food systems, interweaving research and development across formal, natural, and social sciences. Table 5 presents a map of science and innovation focus areas addressing the requirements for achieving food security, food safety, and nutrition security within self-sustainable basic foods systems.

The suggested focus areas are distinct, tailored to address the particular requirements of each subsystem. Scientific and innovative aspects related to food handling, packaging, and storage are the only elements shared across the raw food and feed production, food and feed processing, and food and feed market subsystems. In addition to the subsystem-specific focus areas, there is also a proposed list of focus areas that are applicable to the entire self-sustainable basic foods system. It is crucial to recognize that the list of science and innovation focus areas is by no means exhaustive. Instead, the suggestions made are intended to spark further discussion and should be adapted to align with the unique situation of each country that is either considering or already engaged in the transition toward a more self-sustainable basic foods system.

5.2. Enhancing the production and consumption of bioactive compounds through local foods

Food serves a role beyond merely supplying essential nutrients and catering to our taste preferences; it is also fundamental for our overall well-being. The importance of bioactive compounds in bolstering the sustainability of food systems, especially concerning nutrition security, is rising throughout the entire food supply chain. As highlighted in Table 5, the recommended focus areas stress the necessity to enhance nutrition security by safeguarding and, if feasible, enhancing the stability and functionality of bioactive compounds in both food and feed across the supply chain, from farm to consumer. Thus, it becomes crucial to ensure the availability of physiologically active compounds with distinct bioactivities that benefit our physical health and mental well-being.

Within food and feed processing subsystem, fermentation is one of the most widely adopted methods for preserving the quality and quantity of bioactive compounds in food and feed. Fermentation, whether anaerobic (as observed in lactic acid and alcohol fermentation) or aerobic (as seen in alkali and fungus fermentation), plays a significant role in human dietary practices. According to Wilburn and Ryan (2017), fermented foods and beverages are fundamental elements of the nutritional heritage of societies worldwide. They are deeply entwined with the cultural history of various ethnic groups. Naturally fermented foods contain both functional and non-functional microorganisms. The former can boost the accessibility of food components, enhance sensory characteristics, and ensure food safety. They may also break down anti-nutritional elements and harmful constituents, generate antioxidants and antimicrobial substances, foster probiotic functions, and produce health-enhancing bioactive compounds (Tamang et al., 2016).

Fermentation enhances the taste, appearance, shelf-life, digestibility of nutrients, and overall nutritional quality of legumes. It aids in reducing non-nutrient compounds found in legume seeds, such as protease inhibitors, oligosaccharides, phytates, and lectins (Frias et al., 2017). Fermentation also extends the shelf life of perishable foods (Terefe, 2016), improves the bioavailability of minerals, and enhances the digestibility of proteins and carbohydrates, along with the sensory attributes of the final product (Altay et al., 2013; Utami et al., 2016). Furthermore, fermentation contributes to the detoxification and breakdown of undesirable substances like phytate, tannins, and polyphenols (Ansorena and Astiasarán, 2016; Terefe, 2016). Fermented foods may also exhibit improved nutritional and functional qualities due to the transformation of substrates and the development of bioactive or bioavailable end products (Blandino et al., 2003; Bilgiçli et al., 2006). For instance, a noteworthy subgroup of bioactive peptides formed during fer-

Table 5. Map of Science and Innovation Focus Areas in a Self-sustainable Basic Foods System.

Self-sustainable Basic Food System Subsystems	Science and Innovation Focus Areas		
	Food Security	Food Safety	Nutrition Security
Raw food and feed production	enhanced local basic land and aqua raw production capacity (vertical gardening, weather manipulation, aqua culture, agricultural machineries, regenerative farming, etc.); advancements of local indigenous resources; safeguarding freshwater resources; improve biodiversity; sustainable land management (reforestation and restoring degraded lands acceleration); expanding agroforestry.	food hygiene and cleaning; food handling; food packaging and storage; improve agricultural management (use of natural pesticides, antibiotics, etc.).	advancement of animal and plant breeding programs to face severe weather and climate change; improve biodiversity; reduce food waste on farms; increase the content of bioactive compounds in food and feed.
Food and feed processing	enhanced local food manufacturing capacity; advanced marketing of local foods: form variety.	food handling; food packaging and storage; anti-allergens; organic food coloring and other natural ingredients; culture of hygiene practices in food processing.	advancement in food processing technology; fortification; product formulation; maintain the stability and functionality of bioactive compounds in food and feed.
Food and feed market	recognition of alternative local foods; waste reducing stock patterns; advanced marketing of local foods: branding, packaging; shelf life extension through bioactive compounds.	food handling; food packaging and storage; culture of hygiene practices in food preparation and handling.	healthy diets, including local based; local consumer behavior and perception; advanced marketing of foods rich in bioactive compounds: branding, packaging.
Food consumption	local culture resilience; waste reducing consumption patterns.	culture of hygiene practices in food preparation and consumption.	healthy consumption patterns: quantity and quality (reduced sugar, salt, fat intake); nutrition balance; improve the intake of food rich in bioactive compounds.
Supply chains	enhanced security and shorter supply chains.	food/feed traceability.	reducing food waste within supply chains; improve food storage.
Food and feed loss and waste management	food loss and waste repurposing for feed, fertilizer, and energy conversions.	secure waste disposals.	recovery of bioactive compounds in the waste stream.
All subsystems	reforestation; food resilience to face climate change; mitigate water pollution; environment rehabilitation programs; advancements of reliability and capacity of renewable energies; workforce education and training on advanced machineries; social structure construction: long-term financial security (e.g. personal savings, pensions); access to basic expected life amenities (e.g. internet); education system (output geared toward meeting the realistic needs of the country); reshaping career expectancy trends that better serve the nation's need for raw food production and manufacturing (shifting from social media content providers, online trading, etc.); social transition from traditional farming to advanced farming (utilizing machineries); mass development of advanced fishermen; immigration policies that protect local lower end occupations; food import policies that synergizes with local production, including transparent and accountable financial flow from food imports; stronger local food culture: tax exemptions.		

mentation include Angiotensin-1 converting enzyme (ACE) inhibitor peptides. These ACE-inhibitor peptides in fermented products have demonstrated antihypertensive effects and are recommended as a non-pharmacological remedy for hypertension (Beltrán-Barrientos et al., 2016).

Additionally, lactic acid bacteria have diverse effects, including the modulation of immunological parameters, reduction of inflammation, and antimicrobial activity (Kim et al., 2017). They have also been associated with antitumor and anti-fungal properties, reduction in cytokine production associated with aging (Muscettola et al., 1994), and a decrease in serum cholesterol, which is of particular interest in preventing cardiovascular diseases (Ogunremi et al., 2015), among other benefits. These effects are attributed to the microorganisms present, their metabolic activities, and the biotransformations occuring during fermentation.

Aging is characterized by a gradual decline in physiological function and homeostasis, leading to age-related injuries, diseases, and mortality. Fermented food products hold promise due to the immunomodulatory effects of microorganisms and the increased presence of bioactive compounds. Indeed, several anti-aging benefits have been reported, some of which are associated with specific compounds like genistein and daidzein in soybeans, while others remain to be discovered.

In establishing self-sustainable basic food systems, the use of local staple foods and reducing food waste is widely recognized as a critical strategy to enhance global food security. Leveraging waste products in the production of fermented foods can yield dual or even multiple advantages. When agricultural waste products are improperly disposed of into the environment, they can lead to environmental pollution and adversely affect both human and animal health. A significant portion of agro-industrial waste remains untreated and vastly underutilized. Therefore, it is imperative to explore the effective utilization of agro by-products through solid-state fermentation, which can enhance their nutritional, functional, and other health-promoting properties. This approach holds significant promise in addressing this issue (Sadh et al., 2018; Chawla et al., 2020; Andayani et al., 2020).

6. Conclusion

Food systems have recently been disrupted by significant shocks, most notably the COVID-19 pandemic, the ongoing war in Ukraine, and the accelerated climate crisis with extreme weather events. Self-sustainability of food systems needs to be mainly enhanced through science, technology, knowledge, and innovations. Increased international sharing of all related science, technology, and innovation is essential for that. Utilizing a newly proposed sustainable food system framework, a more intricate and comprehensive analysis of the requisite science and innovation focus areas is suggested. This analysis encompasses all subsystems within the core food system, aimed at ensuring food security, food safety, and nutrition security including securing high intake of bioactive compounds from local foods. The identification of these needs were made based on deeper understanding of the mechanisms underlying each subsystem, which address the fundamental rational for countries to initiate movement towards self-sustainability as well as anticipating potential challenges during the planning and implementation phases of transitioning to self-sustainable basic foods systems. There exists the potential for this framework to be refined and adapted by other scholars to better align with the unique circumstances of each country seeking to transition or already progressing toward a more self-sustainable basic foods system. Furthermore, this framework can serve as a valuable tool for scholars, ensuring comprehensive coverage and equitable progress in science and innovation across all focus areas through forthcoming multidisciplinary research and development endeavors.

Endnotes

[1]https://www.fao.org/faostat/en/#data/FS.
[2]Severe food insecurity is characterized by feeling hungry but not eating, or not eating for an entire day, due to lack of money or other resource (Food Insecurity Experience Scale, https://www.fao.org/in-action/voices-of-the-hungry/faq/en/).
[3]Undernourishment is the proportion of the population whose dietary energy consumption is less than a pre-determined threshold (FAO, https://www.fao.org/3/al936e/al936e00.pdf).
[4]Weight-for-height <-2 SD of the WHO *Child growth standards* median (World Health Organization, https://www.who.int/data/nutrition/nlis/info/malnutrition-in-children).
[5]Height-for-age <-2 SD of the WHO *Child growth standards* median (World Health Organization, https://www.who.int/data/nutrition/nlis/info/malnutrition-in-children).
[6]Weight-for-height >+2 SD of the WHO Child growth standards median (World Health Organization, https://www.who.int/data/nutrition/nlis/info/malnutrition-in-children).
[7]Particularly China, Japan, Iran, Iraq, India, and Pakistan.
[8]Particularly the United Kingdom, Germany, France, Spain, Portugal, Sweden, Italy, Finland, Estonia, and Belgium.
[9]Particularly Morocco, Algeria, Kenya, Somalia, Ethiopia, and Madagascar.
[10]Particularly Uruguay, Argentina, Paraguay, Chile, and Brazil.
[11]Particularly the United States and Canada.
[12]Particularly Pakistan, India, the Philippines, Korea, Japan, the United Arab Emirates, Yemen, Iran, and Saudi Arabia.
[13]Particularly Australia.
[14]Particularly Brazil and Venezuela.
[15]Particularly Niger, Nigeria, Chad, South Sudan, South Africa, Madagascar, Mozambique, and Malawi.
[16]Particularly the United States and Canada.
[17]Particularly Cuba, Dominican Republic, and Puerto Rico.
[18]Particularly Spain, France, Italy, Slovenia, Austria, Czechia, the United Kingdom, Netherlands, and Belgium.
[19]Particularly the United States and Canada.
[20]Particularly the United Kingdom, Iceland, Greece, and France.
[21]Particularly Libya.
[22]Particularly Argentina and Chile.
[23]Temperature anomaly means a departure from a reference value or long-term average. A positive anomaly indicates that the observed temperature was warmer than the reference value, while a negative anomaly indicates that the observed temperature was cooler than the reference value.
[24]Calculated based on data retrieved from https://www.energyinst.org/statistical-review/.
[25]Ibid.
[26]Ibid.
[27]Ibid.
[28]Ibid.
[29]Ibid.

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