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Climate risks for the European food system and policy preparedness

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ABSTRACT

Climate change increases the risk of disruptions across European food systems, including the productivity of crops, livestock, and fisheries, as well as the stability of global trade and markets. These risks propagate through food storage, processing, distribution, and ultimately access to safe and nutritious food, with socio-economic factors determining household vulnerability. The risk of climate impacts to European food systems is subject to uncertainties due to the complex interactions between climatic, ecological, and economic drivers, and the potential for simultaneous stressors both within Europe and globally. Strengthening resilience requires integrated adaptation strategies across production, supply chains, trade, and social protection, coupled with governance approaches that address systemic risks, promote sustainability, and ensure equitable access. Current EU policies address many relevant aspects, but lack coherence and ambition. While adaptation options exist for various climate risks, gaps remain in managing climate risks to food processing, transport, retail, and social vulnerability, highlighting the need for coordinated, forward-looking risk management and for developing strategies for transformative adaptation across the food system.

Contents

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1. Introduction

Climate change is already negatively affecting global food production and food security, and these impacts are projected to worsen in the coming decades (IPCC, 2022), though the impacts in Europe are expected to be less negative than in most other regions (Jägermeyr et al., 2021), but with large variations (European Environment Agency, 2024). Southern Europe in particular is already suffering from recurring adverse weather and climate conditions and extremes, especially droughts (Webber et al., 2018). Food production and functional food systems depend on a host of, often related, climatic and non-climatic drivers. Climate change causes increases in frequency and intensity of extreme events, such as droughts, heatwaves, and excessively wet conditions, alongside general shifts in crop growth suitability. European food systems are also affected by climate impacts outside of the region, whether on production, markets, or transport systems. These international risks are transmitted through trade and commodity markets. Non-climatic drivers include biophysical factors such as biodiversity, soil health, and environmental pollution; and socio-economic, political, and institutional factors such as research, risk management, trade, market dynamics, and energy costs. Geo-political tensions and wars, including recent events in Ukraine, Israel/Gaza, and Iran, lead to the destruction of production assets, displaced farmers, higher prices (Bouri et al., 2023; De Winne and Peersman, 2021), and subsequently worsened food access (Bilali and Hassen, 2024), dynamics typically omitted from future agricultural production projections.

Europe is a wealthy continent, which, along with other factors like governance, agency, and knowledge, contributes to high adaptive capacity (Chapagain et al., 2025). European per capita incomes are among the highest in the world on average (World Bank Group, 2025), but wealth distribution across and within European countries is unbalanced.

According to the FAO Food Insecurity Experience Scale (FIES) survey published in the FAO SOFI report (FAO et al., 2025), about 6.8% of the European population is currently moderately-to-severely food insecure, predominantly economically disadvantaged people, women, elderly, and people with disabilities (Garratt, 2020; Zaçe et al., 2020). In 2021, in 37 countries of the WHO European region, 16.3% of survey respondents reported eating only a few kinds of food, and 14.4% reported being unable to eat healthy and nutritious food. Compared to 1981–2010, in 2021 an additional 11.9 million people in Europe are estimated to have experienced food insecurity due to climate change (van Daalen et al., 2024; Dasgupta and Robinson, 2022).

Given the complexity of food systems and their strong interaction with climatic conditions, food security is increasingly subject to systemic risk, requiring novel and comprehensive perspectives to be included in proposed solutions, ranging from macro-policy instruments to local actions. Efforts to strengthen the resilience of European food systems, i.e. to develop capacity to live and develop with change and uncertainty (Rockström et al., 2023), in response to these growing and cascading risks inevitably rely on national and EU-level policies and regulations. Such initiatives must be continuously and critically evaluated to ensure that adaptation and mitigation goals do not compromise food security — which requires maintaining high-quality, efficient agricultural productivity in a sustainable way — and co-benefits of policies are maximized for different domains. This paper, expanding on the first European Climate Risk Assessment's (EUCRA) chapter on food security (European Environment Agency, 2024), provides a comprehensive assessment and review of the climatic and associated non-climatic drivers and uncertainties that influence food production and food security in Europe. On this basis, we discuss how well prepared Europe is for the anticipated climate change impacts and risks on food production, food security and nutrition, approaching these issues from a food systems perspective.

2. Climate risks and changing hazards

Changing climate, adverse weather, and extremes are already affecting European food systems through impacts on food production, processing, storage, logistics, and access. Extreme events are projected to increase in frequency and intensity under climate change (Seneviratne et al., 2021), serving as critical drivers of impacts across Europe (e.g., Beillouin et al., 2020; Vogel et al., 2019) and increasing the risk of cascading effects and shocks along the full food system impact chain. One of the most prominent climate drivers is shifting precipitation patterns, which can increase the likelihood of compounding extreme droughts, heavy rainfall, and floods. More complex drought risks have emerged recently, including large-scale spring-to-summer drought events compounded by heatwaves across central and northern Europe as seen in 2018 (Toreti et al., 2019a; Spinoni et al., 2017). Severe winter droughts, such as in 2022–2023 in western and southern Europe (e.g., Toreti et al., 2023), hit several regions, while rapid flash droughts triggered by low precipitation, high temperatures, winds, and radiation pose new threats to production (e.g., Shah et al., 2022). Within Europe, drought risk is elevated in central, eastern, and southern regions, and comparatively lower in northwestern and northern Europe (Carrão et al., 2016; Rossi et al., 2023). Conversely, excessive rainfall can trigger major crop failures, damage production infrastructure, or impede land access during harvest or sowing. A notable example is the 2016 wheat failure in France, where prolonged rainfall, low radiation, soil anoxia, and fungal diseases combined to cause yield losses up to 55% in certain regions (Nóia Júnior et al., 2023).

Future climate impacts will depend heavily on systemic human drivers, including speed of the energy transition (e.g., Liu et al., 2022), policies (e.g., Stechemesser et al., 2024), diets (e.g., Springmann et al., 2018), and lifestyles (e.g., Wynes and Nicholas, 2017). Regardless of emission abatement trajectories, certain warming levels and intensifying extreme events are already locked in due to historical emissions (Intergovernmental Panel on Climate Change, 2023). Generally, climate impact projections are subject to large uncertainties originating from radiative forcing trajectories (e.g., RCPs van Vuuren et al., 2011), interacting socio-economic pathways (e.g., SSPs Riahi et al., 2017), global climate model selection (e.g., McSweeney and Jones, 2016), and unresolved processes within both climate and agricultural impact modeling frameworks (Folberth et al., 2019; Nóia Júnior et al., 2025; Müller et al., 2021; Wang et al., 2024). Despite harmonization efforts by communities like ISIMIP, the literature on climate impacts remains fragmented and rarely reflects the full range of model and scenario uncertainty (e.g., McSweeney and Jones, 2016; Müller et al., 2021). Evidence thus reflects a highly diverse and heterogeneous body of literature, making direct comparisons across timescales, conditions, and crops challenging. Furthermore, potential climate tipping points in the earth system represent a particular concern for food production systems (e.g., McKay et al., 2022; Ripple et al., 2024). While the timing of tipping points remains highly uncertain, risks scale disproportionately with global temperature change, and their disruptive nature risks destabilizing broader socio-economic systems (Ritchie et al., 2020). Disruptions to ecosystem services, water cycles, and infrastructure may unfold at or above a 1.5 °C global warming threshold, but high uncertainty continues to impede governance follow-up (Lenton et al., 2023).

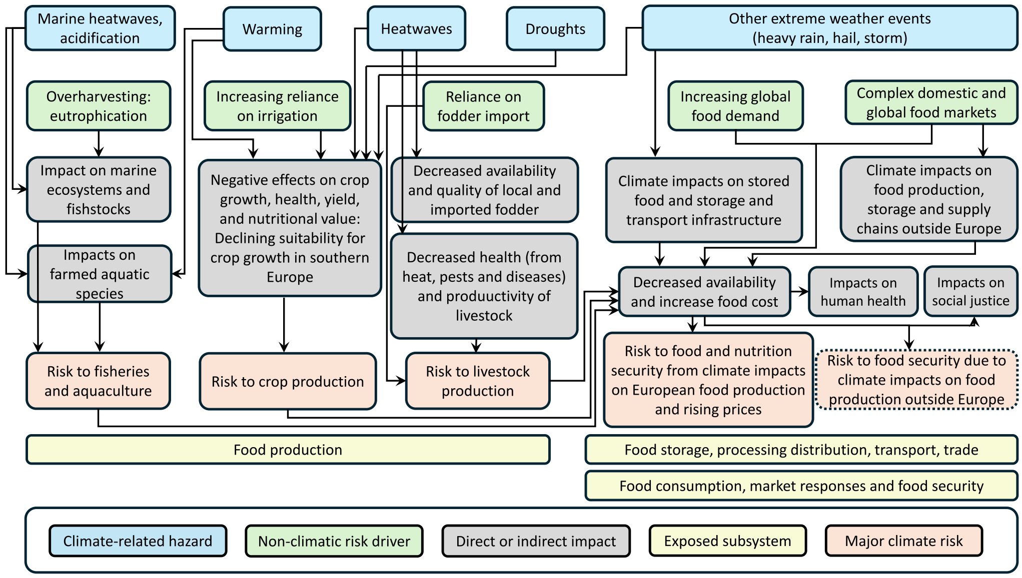

Fig. 1. Impact chain of climate risks for European food production and security.

3. The climate risk impact chain for food system

Climate change interacts with climate variability to affect crop growth, livestock, fisheries, and aquaculture production through complex, overlapping direct and indirect mechanisms. Strong consensus indicates that climate change will primarily harm regions that are already warm and dry, whereas currently cooler areas will face less severe impacts or even experience potential benefits (Jägermeyr et al., 2021; Franke et al., 2022). Following primary production, food must be processed, stored, and distributed within separate but strongly interlinked supply subsystems.

European food systems are highly coupled with international markets. International climate impacts alter domestic food availability directly through the trade of food commodities, or indirectly by driving price volatility and spikes in international markets. Indirect impacts also manifest through supply chains for critical production inputs, such as fertilizers. Similarly, food systems are intimately connected to other climate-exposed sectors, including terrestrial and aquatic ecosystems, freshwater supply, energy, and transport infrastructure. Climate risks to these interconnected sectors (e.g., European Environment Agency, 2024) consequently propagate as indirect risks to food production in Europe. The different subsystems have been studied unevenly, with crop production receiving the most research focus, while food processing, storage, and logistics receive significantly less attention. To map these vulnerabilities, we identify potential climate entry points across the European food system by tracing a systemic climate risk impact chain (Fig. 1), reflecting a systemic perspective where disruptions can cascade into broader risks.

Substantial baseline climatic differences exist across Europe, ranging from the arid Mediterranean to cool, humid Scandinavian environments. Consequently, heterogeneous climate impacts will necessitate transformative adaptation in highly vulnerable areas, while opening up new production potentials in others (Minoli et al., 2022; Franke et al., 2022).

3.1. Crop production

A large body of research addresses individual and combined climatic impacts on annual crop productivity (e.g., Webber et al., 2018; Ciscar et al., 2018; Jägermeyr et al., 2021), elevated CO_2 interactions (Toreti et al., 2020), adaptation pathways (e.g., Minoli et al., 2022; Asseng et al., 2019; Zabel et al., 2021), and sustainable intensification (e.g., van Ittersum et al., 2025; Liu et al., 2018). Although European crop productivity appears globally among the least negatively impacted (Jägermeyr et al., 2021; Rosenzweig et al., 2014), strong intra-continental heterogeneity exists. Southern and central European regions face severe climate-driven yield declines, while northern latitudes may experience overall positive shifts (e.g., Jägermeyr et al., 2021; Carozzi et al., 2022; Hristov et al., 2020).

Because most research focuses on a few primary staple crops and simplified mono-cropping systems, climate knowledge regarding alternative crops and production configurations remains limited both in Europe and globally (Zabel et al., 2025). This knowledge gap hinders comprehensive evaluations of future adaptations across the broader food production system. For major staples, projections indicate increased inter-annual variability and extreme events (Jägermeyr et al., 2021), though the capacity of current crop models to realistically capture historically low-yielding years remains limited (Schewe et al., 2017; Kornhuber et al., 2023) due to unresolved representations of complex crop-climate interactions (Nóia Júnior et al., 2025).

Extreme events, such as heavy precipitation, storms, heatwaves, and late frost (in combination with earlier growing seasons), amplify yield volatility and can destroy seasonal harvests (Schauberger et al., 2016), or permanently damage farm infrastructure, soils, and water reserves (e.g., Borrelli et al., 2020). Droughts have already inflicted severe damages on European agriculture (e.g., Fioravanti et al., 2025) and are projected to further drive yield declines for staples across Europe and particularly the Mediterranean (Rossi et al., 2023; Webber et al., 2018). Summer droughts comparable to the exceptional 2018 event are projected to become the norm in central and northern Europe by the 2050s (Toreti et al., 2019a). As southern Europe simultaneously faces recurrent droughts and declining spring-to-summer precipitation, the historical "see-saw" water mechanism — where favorable conditions in one region offset losses in another — will become unavailable to counterbalance production shocks at the European level or prevent international risk propagation. Persistent, recurrent drought events compound these impacts over longer timescales; in 2022, over two-thirds of the EU territory experienced severe drought conditions that heavily affected agricultural sub-sectors. Conversely, excessively wet conditions and heavy rainfall inflict substantial direct crop damage, which is frequently compounded by heightened pest and disease pressures (Nóia Júnior et al., 2023; Fu et al., 2023). With escalating risks of simultaneous crop failures across multiple production regions (Goulart et al., 2023), Pan-European yield compensations like those observed in 2018 (Beillouin et al., 2020) are becoming increasingly unlikely.

Perennial crops face accelerating threats from extreme heat (Parker et al., 2020) and reduced winter chilling required to maintain productivity (Atkinson et al., 2013; Meza et al., 2023). Advanced flowering paired with erratic spring weather further increases the risk of early spring frost damages (e.g., Ceglar et al., 2019). Hail storms are already responsible for a large fraction of damages to fruit trees across Europe (Peláez et al., 2025) and may become more important for perennials and southern Europe (Kahraman et al., 2025; Raupach et al., 2026). Under high-emission pathways (RCP8.5), southern Europe is projected to face large-scale suitability losses for perennial fruit production of apples, cherries, grapes, and olives by the late 21st century (Meza et al., 2023). Viticulture, while not directly critical for food security, constitutes a major economic sector representing 0.8% of European GDP that is highly vulnerable across southern and eastern Europe (Tscholl et al., 2024).

Annual and perennial crop production relies heavily on irrigation, positioning agriculture as the largest water-consuming sector in Europe. Crop production is thus inextricably linked to the water sector and highly sensitive to climate-driven supply constraints (EEA, 2021), which potentially limits the long-term viability of irrigation as an adaptation strategy (Elliott et al., 2014).

Plant pests and pathogens remain leading drivers of agricultural losses globally (Chakraborty and Newton, 2011). In Europe, climate anomalies can trigger severe fungal outbreaks (Figueroa et al., 2018), uncontrolled insect infestations (Meissle et al., 2010), or early pathogen infections (González-Jiménez et al., 2023) that cause severe local yield shocks. While crop protection frameworks remain broadly effective, repeated reliance on single-mode-of-action chemicals reduces efficacy and accelerates resistance pathways (Lamichhane et al., 2015). Perennial systems are uniquely vulnerable due to the year-round presence of pathogens, extended lifespans that limit cultivar replacement, and stringent regulatory constraints (Stukenbrock and Gurr, 2023). Mounting evidence confirms that climate change enhances pest and disease prevalence. Drought, heat, and excessive humidity weaken crop immune defenses, increasing susceptibility to pathogens (Singh et al., 2023).

Warming is actively reshaping pest biogeography, driving poleward range expansions (Raza and Bebber, 2022) that are further accelerated by international trade and transport networks (Pyšek et al., 2020). Altered ecological network interactions among hosts, vectors, and pathogens (Grünig et al., 2020) intensify outbreak diversity and severity (Deutsch et al., 2018; Singh et al., 2023). Emerging outbreaks affecting perennials include *Xylella fastidiosa* incursions in olive groves (Godefroid et al., 2019) and grapevines (Giménez-Romero et al., 2024), which incur severe economic damages (Schneider et al., 2020). By 2050, Mediterranean wheat production faces a projected 10% decline driven by more frequent blast epidemics (Pequeno et al., 2024). Furthermore, food safety is increasingly threatened by persistent *Fusarium* mycotoxin contaminations that exceed established regulatory thresholds (Casu et al., 2024; Johns et al., 2022). These evolving biological threats increasingly challenge existing management frameworks, which remain underprepared for the rapid emergence of novel or historically minor pests (Catarino et al., 2015; Early et al., 2016).

Pollinator-dependent crops — including perennial fruits, nuts, oilseeds, and pulses — represent a substantial share of EU agricultural value and dietary diversity (Aizen et al., 2019; Vallecillo et al., 2018). Approximately one-fifth of the EU's cultivated area depends directly on animal pollination (Schulp et al., 2014), a share that is rising due to shifting consumer preferences (Aizen et al., 2019). Even predominantly self- or wind-pollinated crops like maize benefit in yield and quality from insect visitation (Bartomeus et al., 2014). However, pollinator populations are declining across Europe due to interacting climatic and non-climatic pressures, including land-use intensification, pesticide exposure, and habitat fragmentation (Dicks et al., 2021; Goulson et al., 2015). Climatic pressures jeopardize pollinator survival via thermal stress (Walters et al., 2022), phenological desynchronization (Freimuth et al., 2022), and altered pathogen–parasite dynamics (Manlik et al., 2023). Collectively, these stressors severely degrade pollination efficiency (Garibaldi et al., 2013), threatening stable crop production (IPBES, 2016; Rader et al., 2016). The full extent of these impacts may remain obscured for decades due to delayed ecological feedbacks and lag responses (IPBES, 2016). Consequently, projections of crop–pollinator dynamics under a warming climate carry high uncertainty due to limited understanding of how interaction losses cascade through plant–pollinator ecological networks (Vasiliev and Greenwood, 2021).

3.2. Livestock production

Climate change is expected to negatively impact European livestock production and its associated economic value by compromising animal welfare, health, reproduction, and the quantity and quality of meat, eggs, and dairy products (IPCC, 2022). Direct impacts manifest through escalating heat stress and precipitation extremes (Wolfenson and Roth, 2019; Thornton et al., 2021; North et al., 2023), while indirect drivers include altered fodder production, quality, and composition, elevated pest and disease pressures, and drinking water shortages (Godde et al., 2021; IPCC, 2022; Phelan et al., 2016; Lacetera, 2019; Rojas-Downing et al., 2017). Despite their potential importance, these climate impacts are frequently neglected in broader assessments or captured only indirectly via feed price fluctuations and trade dynamics of dairy and meat commodities (Boere et al., 2019; Ciscar et al., 2018).

The magnitude of these impacts depends heavily on the extent of livestock exposure to weather and climate variables. Direct climate pressures stem from elevated temperatures and relative humidity that impair sweating efficiency, which is measurable via a temperature–humidity index (North et al., 2023). Consequently, climate impacts on poultry and swine are projected to remain limited across large parts of Europe due to structural temperature control in closed housing environments. In contrast, production vulnerabilities for poultry and swine are expected to be higher in southern Europe, where open housing systems are dominant (Bednar-Friedl et al., 2022).

Projecting climate-driven changes in animal disease incidence remains highly complex and uncertain due to multi-factorial transmission dynamics. African Swine Fever transmission to domestic swine, for instance, occurs via contact with infected conspecifics, wild boars, soft ticks, or contaminated feed, water, semen, farm personnel, equipment, and transport vectors (Guinat et al., 2016; Liu et al., 2021). Most of these transmission pathways and their underlying efficacy are sensitive to climate change, human behavior, and climate- or anthropogenically-induced ecosystem modifications. While impact models accounting strictly for first-order climate effects tend to project geographic range shifts with little net increase in total affected area (Lafferty, 2009), recent complex network analyses show a different trend. Specifically, frameworks integrating cross-species transmission vectors indicate potentially large increases in infectious disease risks under the combined pressures of changing land use, declining biodiversity, and mounting population pressures (Brooks et al., 2022; Carlson et al., 2022).

3.3. Fish and aquaculture production

Although the Baltic Sea and other European marine habitats are among the most rapidly warming water bodies globally, the exact effects of climate change on European fisheries remain poorly understood. Climate change drives highly complex interactions across abiotic variables — such as water temperature, salinity, acidity, nutrients, sea level, and sea ice — and biotic elements, including food availability, species and food web compositions, reproduction, and migration, affecting the abundance, distribution, productivity, and life cycles of fish and marine organisms (Payne et al., 2021; Issifu et al., 2022). Research on climate impacts within fisheries remains fragmented, frequently focusing on a narrow selection of species and regions while neglecting broader social and economic implications (Predragovic et al., 2023). Parallel to the livestock sector, research targeting climate impacts on fisheries remains scarce. A global model intercomparison study by Lotze et al. (2019) suggests that marine animal biomass will decline under climate change, with higher trophic levels suffering the largest contractions under high-emission scenarios.

Diverse climate pressures confront European coastal zones and fisheries, including changes in distribution ranges, water temperatures, and productivity profiles, exhibiting pronounced spatial heterogeneity across Europe.

Climate change impacts on wild fish supplies are heavily compounded by unsustainable fisheries management (Barange et al., 2014), yet empirical evidence is restricted to few species and remains overly focused on narrow biological metrics rather than evidence-based marine ecosystem management (Predragovic et al., 2023). While climate change is projected to shift fish distributions, current knowledge is insufficient to inform how these migrations will affect regional European catch quotas designed to maintain management sustainability (Baudron et al., 2020).

Marine productivity is tightly coupled with agricultural dynamics and terrestrial climate impacts. More frequent heavy precipitation events under climate change accelerate terrestrial fertilizer runoff, intensifying eutrophication risks in adjacent water bodies (Rozemeijer et al., 2021) and worsening temperature-dependent harmful algal blooms, which deplete dissolved oxygen from oceans and lakes during their decay, leading to 'dead' zones and widespread die-offs of fish and other water life (FAO, 2020). Although regional nutrient (nitrogen and phosphorus) levels diminished between 1980 and 2023 (EEA, 2025a), baseline concentrations remain elevated in the North, Baltic, and Black seas, alongside parts of the Mediterranean coast, leaving these areas highly vulnerable to such events. Marine ecosystems are equally sensitive to the opposite hydrological extreme, as seen when the exceptional 2018 European heatwave and drought conditions severely limited freshwater and nutrient transport to coastal zones such as the German Bight. This reduction altered coastal and pelagic productivity through complex interactions among solar radiation, water stratification, algae growth, and zooplankton grazing, highlighting the need for a better understanding of complex marine ecosystems and their implications for fish production (Kaiser et al., 2023).

Aquaculture is a rapidly expanding production sector (Fao, 2024), with global output projected to roughly equal wild capture fisheries by 2030. Compared to Asian systems, European aquaculture remains relatively small, accounting for approximately one-fifth of the total economic output of EU fisheries (Eurostat, 2019). In sharp contrast to inland-dominated systems like China, European aquaculture occurs predominantly in marine environments. Aquaculture operations face frequent disruptions from extreme events, including floods, pathogen and parasite outbreaks, warming-induced jellyfish blooms, acidification, and hypoxia (Cao et al., 2023).

Climate projections indicate a potential expansion of finfish habitats, which may increase production across specific regions until critical thermal tolerance limits are breached, whereas total bivalve habitats in the Northern Hemisphere are projected to contract (Bezner Kerr et al., 2022).

Mirroring livestock production, aquaculture relies heavily on imported, high-protein feed components (Huntington, 2022), exposing the sector to climate shocks outside Europe. Water availability and quality are also under pressure within terrestrial aquaculture systems due to intensifying freshwater shortages (Troell et al., 2014). Substituting marine-derived feed ingredients with terrestrial feed alternatives threatens to further exacerbate land-based freshwater deficits (Pahlow et al., 2015). Direct climate-driven impacts on cultured species in Europe are projected to be negative but moderate compared to crop production systems. However, the sector remains highly vulnerable to short-term disruptive extremes and indirect, feed-trade-mediated climate impacts (Huntington, 2022).

3.4. International trade

Global patterns of climate-change impacts will almost certainly lead to negative changes in production outside of the EU and the resulting impacts on trade flows and food prices will translate into higher food prices in Europe (Nelson et al., 2014; Hedlund et al., 2022).

Because strong negative climate-change impacts on crop productivity outside of the EU are projected, large market spill-over effects could result in increased production in both Northern and Southern Europe through higher demand for some agricultural commodities outside of Europe, which could in turn result in higher producer prices, better farmer incomes, and modest increases in consumer prices within the EU (Hristov et al., 2020).

The EU is the world's largest single market, with numerous international trade dependencies ranging from food and animal feed, fuels, raw materials, and consumer goods (Szczepański, 2021). Europe is a net importer of some agricultural commodities, ranging from seafood products, fruits/nuts, oilseeds, to protein crops (animal feed) (Eurostat - European Commission, 2024). Another important import dependency of Europe regards mineral fertilizer and natural gas needed to produce nitrogen fertilizer in Europe (Benton et al., 2022). Even under near-term scenarios, the stress put on agricultural commodity trade by highly variable, uncertain and decreasing yields due to climate change is likely to increase volatility, trigger price spikes, and threaten the stability of commodity markets (Chatzopoulos et al., 2021; Adams et al., 2021). For example, Ercin et al. (2021) project that nearly half of the EU's agricultural imports will be highly susceptible to global droughts due to climate change by 2050.

Global food trade is dominated by a few major global producer countries. Their different sensitivities to climate-change impacts, and associated instabilities in trade network may amplify impacts and threaten food security (Hedlund et al., 2022). Of particular concern is the increasing risks of simultaneous multiple major breadbasket failure due to compound events and concurrent extremes (Gaupp et al., 2020; Toreti et al., 2019b). Demographic development and associated food demand, in particular in Africa, are important drivers of future global food demand, and influence trade dependencies (Popp et al., 2017). There is a high potential for increasingly tense geopolitical dynamics and geo-economic fragmentation, as countries — particularly large agricultural producers — reckon with their own vulnerability to climate change. Weaponizing food trade, may exacerbate the risks from climate change, with increased food autonomy and collaboration with small groups of countries to manage transboundary risks emerging as potential solutions (Vigani et al., 2024; Talebian et al., 2024).

3.5. Food storage, distribution, and processing

Food commodities reach consumers through sequential supply stages including storage, processing, packaging, distribution, retailing, and marketing. Efficient logistics rely fundamentally on robust, uninterrupted rail, road, and inland waterway transportation networks. Operating costs across this value chain are highly sensitive to energy prices, which directly pass through to retail food prices for consumers (EC, 2023; Bezner Kerr et al., 2022). Climate-driven damage to stored food threatens to reduce market availability while escalating waste and overhead costs, particularly for highly perishable, nutrient-rich items like fruits, vegetables, fish, meat, and dairy or commodities that are transported over long distances (Bezner Kerr et al., 2022; FAO et al., 2018). Extreme weather events can disrupt this network, e.g., triggering power grid failures that compromise cold storage systems or physically damaging transport infrastructure. Furthermore, prolonged exposure to high temperatures and humidity shortens post-harvest shelf life, exacerbating losses from spoilage and pests while escalating food safety risks from mycotoxins and food-borne pathogens (Bezner Kerr et al., 2022; Moretti et al., 2019).

Climate impacts on critical inland waterway bottlenecks vary regionally based on shifting hydrological cycles and localized water demands (Christodoulou et al., 2020; Vinke et al., 2022). Projected increases in average precipitation and accelerated snow-melt may temporarily alleviate low-water shipping constraints in certain European basins, though the exact timing and magnitude of these processes remain highly uncertain. Nevertheless, across all modeled scenarios, the threat of severe drought to inland shipping remains profound, as intensifying extreme events outpace localized improvements in baseline navigability (Rossi et al., 2023). Regions characterized by high natural hazard exposure and rigid, non-diversified transit networks exhibit the greatest systemic vulnerability to these distribution shocks (Tchonkouang et al., 2024). This vulnerability is amplified globally by a structural reliance on a limited number of export and transit choke points, a systemic risk recently underscored by shipping disruptions in the Black Sea, the Suez Canal in 2021, or the Strait of Hormuz (Rose et al., 2023; Arndt et al., 2023; Tran et al., 2025).

Food processing encompasses all post-harvest transformations — such as milling, pasteurization, freezing, and packaging — required to render raw commodities shelf-stable or ready for consumption. These energy-intensive processing facilities face direct physical damage and operational downtime from extreme weather events like intense storms and flooding (FAO et al., 2018).

As shifting climate suitability alters regional production baselines (Franke et al., 2022; Ceglar et al., 2021), entire supply chains must dynamically relocate storage, processing, and distribution hubs northward to adapt sustainably. Concurrently, global warming threatens cold chain integrity, increasing the incidence of temperature-sensitive foodborne pathogens like *Salmonella*, *Campylobacter*, and *E. coli* (James and James, 2010; EFSA et al., 2020).

Southern Europe faces the most acute structural pressure due to its naturally warmer baseline climate and high concentration of specialized, refrigeration-dependent fruit and vegetable production destined for the broader European market. Beyond baseline food availability concerns, adapting to elevated ambient temperatures drives up storage overheads; for example, an increase from 17 °C to 25 °C drives up cold storage power consumption by approximately 11% (James and James, 2010), depressing producer margins and inflating consumer prices.

4. Access to food and nutritional security

Less attention has been paid in the scientific literature to the relationship between climate change and access to sufficiently nutritious food. Climate change poses a risk to access to food in Europe in the short to medium term primarily through its impact on domestic and international food prices, making food less affordable (Nelson et al., 2014).

Compared to 1981–2010, an additional one million people experienced moderate or severe food insecurity in Europe in 2023 due to a higher number of heatwave days and drought months (Kriit et al., 2026). In 2021, approximately 74 million people, or 16.8% of the EU population, faced poverty risks with incomes falling below 60% of national medians (Eurostat, 2026). Increasing nutritional costs and volatility present severe challenges for economically deprived households who allocate large budget shares to basic sustenance. Higher retail prices compel low-income households to reduce total calorie intake or pivot toward lower-cost, nutrient-deficient diets (EC, 2023).

In Europe, moderate or severe food insecurity is projected to rise by 1.3 percentage points under an optimistic scenario (SSP1-RCP2.6) by 2040–2060 relative to 1995–2014, while under a pessimistic scenario (SSP3-RCP7.0), food insecurity is expected to increase by 4.8 percentage points (Climate Vulnerable Forum and Vulnerable Twenty (V20), 2022). These projections reflect the increasing frequency and intensity of severe heatwaves and droughts that historically carry a negative impact on food security by disrupting regional harvests and driving up prices.

Europe's relatively high reliance on complex and international value chains (West et al., 2023) and on imports of specific agricultural goods (e.g., The Netherlands and Germany for high-protein feed crops) makes the region sensitive to climate-induced shocks that emanate from outside the region and drive up global food prices (Lung et al., 2017; EC, 2025b; Sanz-Cobena et al., 2017). Conversely, climate-driven production shocks within Europe can propagate outward through international trade networks, destabilizing agricultural commodity markets and worsening food insecurity for vulnerable consumers outside the EU (Adams et al., 2021; Chatzopoulos et al., 2021).

Climate change is also increasing the risk of compound events and concurrent extremes, that can result in synchronized harvest failures across multiple global breadbaskets and drive up international prices (Gaupp et al., 2020; Toreti et al., 2019b).

All climate impacts will continue to affect populations unequally: Groups facing higher environmental exposure or lower adaptive capacities exhibit the greatest vulnerability to these impacts (EEA, 2022b). Children and adolescents are disproportionately affected due to developmental requirements for high-quality nutrition. Worsening health and nutritional outcomes linked to climate change are concentrated among European children and pregnant women, driving elevated rates of stunting, wasting, and associated forms of malnutrition (Loopstra et al., 2015; Dasgupta and Robinson, 2023).

Parts of Central, Eastern and Southern Europe (EIB, 2022) face disproportionately negative impacts because these countries typically have higher shares of poor households.

Self-provisioning populations — prevalent among European rural communities, low-income or minority groups — face a higher risk of food insecurity. This risk is acutely concentrated where localized crop yields decline, where remote populations rely heavily on climate-sensitive fisheries or pastoral livestock systems at high altitudes and northern latitudes, or within outermost EU territories (Bednar-Friedl et al., 2022).

Carbon pricing, an important climate mitigation policy, is likely to affect food prices and therefore food access (e.g., Hasegawa et al., 2018), with particular implications for lower-income consumers (Habib et al., 2024). However, in higher-income regions like Europe, the retail price effect of agricultural carbon policies tends to be smaller because primary production accounts for a relatively minor share of final consumer food costs compared to processing, distribution, and retail (Chen et al., 2025).

Future demand for food items strongly affects access and affordability of healthy diets. Household incomes, dietary preferences, consumer prices and availability of different foods, as well as promotion, advertising, and information, are crucial elements in shaping individual food and nutritional choices (EC, 2023). Popp et al. (2017) provide global food demand projections using integrated assessment models and scenarios on demographic developments and per capita consumption of crops and livestock products. Depending on the scenario, food demand ranges from near-stabilization to a strong increase. Bodirsky et al. (2020) suggest a 50% increase in global caloric food demand from 30 EJ in 2010 to 43–47 EJ in 2050, and 36–62 EJ in 2100, with the increases in food demand stemming mostly from India and Africa.

Shifting consumer preferences toward lower-meat diets — driven by health, environmental, and climate considerations — alongside structural efforts to reduce food waste, can alleviate demand for animal feed crops (Bodirsky et al., 2020). In turn, these dietary transitions can increase direct food availability, ease pressure on global grain markets, and lower consumer food prices, thereby enhancing overall food security and health outcomes (Gibson et al., 2026).

5. Solutions

An overarching imperative for European food security, including production and access to food, is to improve the broad resilience of food systems. This requires taking a systemic approach, an explicit consideration of risks, and explicit consideration of societal aspects — such as social justice and solidarity.

Whilst the ecological definition of resilience refers to the ability to absorb shocks and bounce back to an existing state, a wider system perspective considers system properties relating to preparedness, adaptation and transformation. Diversity, redundancy, connectivity, inclusiveness, and adaptive learning are drivers of resilient systems (Rockström et al., 2023).

5.1. Adapting food production systems

Adaptation of food production systems is necessary to reduce climate risks to production. A variety of interacting adaptation strategies can be implemented by farmers and fishers, by service providers, regional and national agencies, covering different measures including economic and financial governance, physical and technological options, nature-based solutions, knowledge transfer, and behavioral changes. Focusing on crop production, several broad action areas include (a) new and adapted varieties and breeds in current production systems, (b) flexible agro-management decisions in conjunction with improved weather forecasts and climate services for tailored information and decision supporting systems, (c) insurances, (d) social safety nets, and (e) agricultural transformation and migration (Loboguerrero et al., 2019).

Breeding and genetic research aim to reduce the impacts of abiotic stresses (such as heat and drought) for different crops (e.g., Sallam et al., 2019; Rosa et al., 2021), livestock (Rust, 2019), and fish (FAO, 2022). The regional success of these cultivars depends heavily on genetic flexibility, as diverse climate impacts require highly specific, localized stress tolerances. However, a critical trade-off exists where stress-tolerant varieties perform well under adverse conditions but yield less than traditional cultivars during favorable years (Moshelion, 2020). Although identifying genetic markers for abiotic stress holds immense potential, widespread commercial market uptake remains limited (Sallam et al., 2019). Furthermore, the entire pipeline from initial development to market release and farm adoption is inherently lengthy and time-consuming (Ganie and Azevedo, 2025).

Building resilience to plant disease spread will require intensified surveillance, response capacity (Stukenbrock and Gurr, 2023), predictive modeling and early-warning systems (Ristaino et al., 2021). At the farm level, forecast-based, adaptive and diversified management is particularly crucial for disease prevention (Stukenbrock and Gurr, 2023). Practices like crop rotations, cultivar mixtures, or alternative varieties enhance system heterogeneity, reducing infection risks and limiting pathogen adaptation (Anderson et al., 2020; Lamichhane et al., 2015). Enhanced international monitoring coordination and sustainable control strategies can further bolster institutional resilience (Singh et al., 2023).

Uncertainty regarding the availability and commercial uptake of adapted crop varieties remains a critical barrier to exploiting their potential (Zabel et al., 2021). Fully exploiting regional agricultural potential may require reconfiguring existing land-use patterns — such as expanding croplands into new areas (Franke et al., 2022) — introducing new risks to biodiversity conservation and ecosystem services (von Jeetze et al., 2023). In temperate climate zones, adjusting sowing dates and selecting long-season cultivars offers substantial potential to avoid seasonal stress periods or realign production with shifting growth suitability corridors (Minoli et al., 2022; Franke et al., 2022). Substituting vulnerable crops with resilient alternatives, such as sorghum instead of maize, or integrating strategic fallow periods helps sustain or increase agricultural production under water scarcity (Richter et al., 2023). Adaptation strategies for perennial cropping systems include chemical substitution of insufficient chilling (Guillamón et al., 2022), sprinkler irrigation for cooling, agroforestry, cultivar and rootstock selection, and orchard relocation (Meza et al., 2023).

Where water resources allow sustainable use, expanded irrigation can effectively reduce the impacts associated with drought and heat stress (Jägermeyr et al., 2017). However, compounding freshwater scarcity and escalating water demands across competing sectors act as key limitations (Elliott et al., 2014; Gerten et al., 2020), particularly during synchronized hydrological and agricultural droughts (Xoplaki et al., 2023). In irrigation-restricted watersheds, on-farm rainwater harvesting can bridge moisture deficits during warm, dry periods (Jägermeyr et al., 2016).

Animal housing could be improved by installing cooling technologies to reduce heat stress, paired with advanced filtration, renewable energy supply, and water delivery improvements to lower the environmental footprint of industrial livestock systems (Rust, 2019). Additionally, introducing silvo-pastoral agroforestry or landscape features provides cost-effective shade for grazing herds.

Fisheries adaptation efforts should target localized risk exposure, prioritizing economic resilience in vulnerable, less-diversified regions like South-East Europe and addressing employment losses in fisheries-dependent communities (Payne et al., 2021). Similarly, aquaculture strategies must address multiple sustainability objectives simultaneously to avoid the risk of maladaptation where improving one metric degrades another (Falconer et al., 2026).

Diversification of on-farm agricultural production can stabilize farm income and production simultaneously (Harkness et al., 2023), while precision farming and conservation agriculture preserve soil health (Costantini et al., 2020). Multifunctional landscape diversification, including mixed crop–livestock systems (De Faccio Carvalho et al., 2021; Dardonville et al., 2023), significantly bolsters climate resilience (Qiao et al., 2022; Hartmann and Six, 2022), compelling livestock, aquaculture, and fisheries systems to diversify both production methods and feed sourcing.

While incremental adaptation is widely documented, transformative adaptation remains under-researched despite its critical role in resource allocation, financial investments, and farm competitiveness (Zagaria et al., 2021). Transformative actions involve structural shifts like migrating production to favorable regions or transitioning to organic frameworks (Muller et al., 2017). These systemic reconfigurations require fundamental shifts in production systems and new technologies to simultaneously pursue future food security and sustainability targets (Carter et al., 2021). Ultimately, whether through incremental or transformative pathways (Vermeulen et al., 2018), building climate-resilient systems that protect soils (Qiao et al., 2022) and support ecosystem services like pollination (EEA, 2025b) remains foundational to future food security (Lipper et al., 2014).

Agricultural insurance protects farm incomes against climate-driven volatility, with weather-index-based options serving as accessible tools for safeguarding infrastructure and production (Schwarze and Sushchenko, 2022); however, subsidized insurance risks disincentivizing other necessary adaptation actions and may become cost-prohibitive under advanced warming (Peláez et al., 2025). Alternatively, community-supported agriculture (CSA) hedges production risks by securing upfront consumer financing, yielding positive but under-evaluated benefits for farm financial stability (Egli et al., 2023).

5.2. Storage, processing, and distribution and trade

Increasing storage capacity can act as a risk mitigation and resilience-increasing tool to address the risk of rising volatility of food prices. Storage expansion is perceived by, for example, soy farmers and traders for the European market as "beneficial, yet expensive" (West et al., 2023).

Beyond buffering physical supplies, strategic storage reserves govern price stability, as historical trade policy shifts and stockpiling strategies largely explained the global price peaks of 2007–08 and 2010–11 (Schewe et al., 2017). International trade also affects food prices (Stevanović et al., 2017) and volatility as prices can respond sensitively even to mere announcements of trade restrictions (Brander et al., 2023). To counter global market fluctuations, the GEOGLAM AMIS monitoring initiative provides transparent, science-driven data on global crop conditions to enhance market visibility (Becker-Reshef et al., 2019). Innovations in bio-based, digestible packaging remain in early development but offer long-term promise for reducing post-harvest losses (Yan et al., 2024). Concurrently, upgrading energy efficiency across processing, transportation, and retail sectors can lower aggregate consumer food prices (EC, 2023).

Retrofitting transportation infrastructure is complex and expensive due to multinational network configurations and multi-stakeholder governance. Incorporating long-term climate horizons exceeding 100 years into infrastructure planning prevents lock-in costs (EEA, 2014); practical measures include integrating porous materials to prevent flooding or using high-albedo bituminous mixtures to avert heat damage on roads.

To reduce vulnerability to international high-protein feed disruptions, European policies incentivize domestic cultivation of soybeans, pulses, and oilseeds (Albaladejo Román, 2025). However, domestic protein expansion cannot fully close the trade deficit and would divert significant agricultural land from other crops or grasslands. For context, displacing current EU soybean imports would require roughly 11 million hectares of land, equivalent to nearly half of the EU's total wheat acreage (Karlsson et al., 2021). Europe also depends heavily on importing fresh fruits and vegetables, with over 50% of supplier markets concentrated in climate-vulnerable nations like Morocco, Egypt, and Turkey (EC, 2025a). Although these specific supply chains lack systematic climate assessments, rising temperatures and expanding droughts render them highly vulnerable (Perez et al., 2021). Sustaining healthy diets can be supported by enhancing production sustainability within source nations, selectively relocating production to Europe, or diversifying crop choices.

Apart from supply-side measures to reduce dependency on imports, demand side measures that reduce demand for livestock products can greatly diminish import dependencies with additional positive side effects for public health, environment and lower GHG emissions (Bodirsky et al., 2025; Gibson et al., 2026). Similarly, minimizing food waste throughout the supply chain liberates vast resource capacities, cuts emissions, and curtails reliance on external feed markets (European Environment Agency, 2024).

5.3. Food system governance

Managing systemic risks, rather than isolated hazards, requires integrated approaches to risk analysis and governance (de Raymond et al., 2021), prioritizing evidence-informed institutional responses and transformative adaptation (Makowski et al., 2023). Low food prices alone will not address food security (Müller, 2026), but create other system inefficiencies (Benton and Bailey, 2019) and while global food demand projections indicate substantial increases in obesity rates, undernutrition and diet-related health risks will concurrently persist (Bodirsky et al., 2020). Transitioning to healthy, sustainable diets comes with multiple co-benefits and could alleviate not only public health burdens but also environmental pressures on climate, land, water, and biodiversity, thereby securing long-term food security (Willett et al., 2019; Sundiang et al., 2025; Beier et al., 2025; Mishra et al., 2025).

EUCRA advocates for a climate-resilient and sustainable food system transformation across all governance levels in Europe and stresses the role for social policies to ensure access to affordable and nutritious diets (European Environment Agency, 2024). Food security, in particular access to healthy food, is strongly affected by socio-economic conditions and drivers, and therefore falls under the remit of policies addressing social justice (Müller, 2026). Macroeconomic development trajectories (van Dijk et al., 2021) and national wealth distribution patterns (Rao et al., 2019) dictate household economic status, heavily influencing food affordability and health equity for marginalized populations.

Robust social protection mechanisms and safety nets insulate vulnerable consumers from price volatility and supply shocks while buffering producers against economic hardship (EC, 2023). Equitable adaptation frameworks, which restructure production and distribution, such as through community-supported agriculture and shortened supply chains, can eliminate systemic inequalities and prevent the generation of new disparities (EEA, 2022a; Davies, 2020) but need more attention in research and policy making. Engaging vulnerable groups in the co-design of adaptation measures can foster socially just climate resilience (EEA, 2022b), increasing the likelihood that structural benefits such as job creation and rural investments offer equitable opportunities.

Beyond domestic social policy, the EU coordinates with international bodies including the FAO (Food and Agriculture Organization of the United Nations and European Commission, 2025) and the World Food Programme to mitigate global nutritional crises. As climate change alters global food systems and shifts geopolitical landscapes, safeguarding global food security demands robust international solidarity and modernized cooperative governance frameworks (Directorate-General for International Partnerships, 2022).

6. EU policies and the food impact chain

A range of EU policies address food production and food security both within and outside Europe. This section focuses on existing policy frameworks and institutional aspects most relevant to managing climate risks along the food impact chain.

EU policies use legislative instruments, such as directives and regulations, alongside non-legislative strategies, that provide the context and guiding principles for multiple policies. All EU policies must comply with the principle of subsidiarity to delineate EU and Member State (MS) competences. Following this principle, individual MS are expected to accept a high degree of responsibility for managing their own climate risks. However, EU level involvement is deemed necessary in cases of cross border impacts that require coordinated responses — for example through shared water bodies — or where climate impacts distort the functioning of the EU single market or affect food availability more broadly. It also concerns the added value of EU-level coordination on adaptation to share experiences and develop more efficient and coherent approaches. Some form of EU coordination will always be needed to avoid that financial support by MS leads to unfair competition.

Fig. 2 provides a schematic overview of how elements of climate risk along the food impact chain are currently addressed by EU policy instruments.

The European Green Deal establishes the EU's overarching sustainability goals, underpinned by the EU Climate Law (European Parliament and Council of the European Union, 2021), which provides the legislative basis for achieving climate neutrality, and mandates enhanced climate resilience and adaptive capacity across sectors. The EU Adaptation Strategy complements this by guiding national adaptation pathways through monitoring and reporting obligations (European Commission, 2021c).

The Farm-to-Fork (F2F) strategy (European Commission, 2020) outlines a vision for sustainable food systems, integrating environmental protection, climate action, biodiversity, food security, affordability, and social equity. However, the 2025 Communication Vision for Agriculture and Food (European Commission, 2025a) shifts attention toward the socio-economic viability and competitiveness of rural areas under geopolitical and climate stress. In many aspects, the Vision de facto replaces F2F. While providing a long-term perspective to 2040, the Vision emphasizes near-term regulatory simplification, whereas the planned legislative framework for a Sustainable Food System — a key F2F milestone — was discontinued.

Addressing shorter-term disaster risks, the Preparedness Union Strategy (PUS) coordinates multi-level responses to climatic and non-climatic crises (European Commission and High Representative of the Union for Foreign Affairs and Security Policy, 2025). Under the PUS, the EU stockpiling strategy aims to secure emergency reserves of essential resources such as food and water (European Commission, 2025c).

The EU Soil Strategy for 2030 (launched in 2021) targets healthy soils across the EU by 2050 to support climate mitigation, resilience, and food security (Panagos et al., 2022; European Commission, 2021a). Initially conceived as a comprehensive, legally binding Soil Health Law, the final instrument, the EU Soil Monitoring Law Directive (European Parliament and Council of the European Union, 2025), was significantly reduced in scope. It mandates no binding target obligations for Member States beyond soil monitoring, with Member States required to transpose its provisions into national law by December 2028.

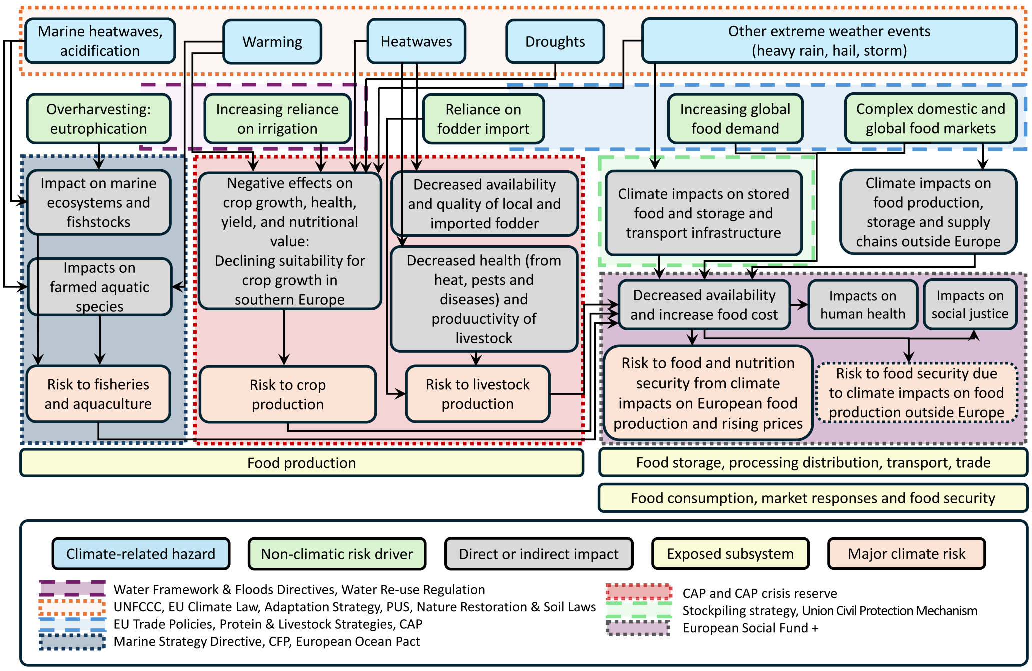

Fig. 2. Policy coverage of the impact chain of climate risks for European food production and security. The Farm-to-Fork (F2F) framework and the Vision for Agriculture and Food cover the entire impact chain and is thus not depicted here. Abbreviations: CAP = Common Agricultural Policy; CFP = Common Fisheries Policy; PUS = Preparedness Union Strategy; UNFCCC = United Nations Framework Convention on Climate Change.

The Nature Restoration law mandates the restoration of degraded ecosystems, to improve biodiversity, climate resilience and ecosystem services. Resilience strengthening efforts will be further scaled up by the forthcoming European Climate Resilience and Risk Management Initiative,[4] which introduces mandatory climate scenarios in regular climate risk assessments and strengthens financing, insurance, and risk management tools.

The Common Agricultural Policy (CAP) and the Common Fisheries Policy (CFP) remain the main sectoral instruments governing European food production. Because the current (2023–2027) CAP and F2F were developed in parallel, integration is limited, leaving progress toward sustainability objectives largely dependent on Member State commitments. Risk management instruments under the CAP cover ~14% of EU farms (European Commission, 2023), implemented under the CAP via so-called national strategic plans. In several MS they are complemented by national schemes. The CAP also provides an annual crisis reserve of 450 million Euros for market shocks, pests, diseases, and extreme events. The Food Security Crisis and Response Mechanism (EFSCM) provides information and high-level advice to enhance preparedness for threats to EU food security (European Commission, 2026; Magnuszewski et al., 2026).

The CFP focuses on fisheries and aquaculture, historically emphasizing stock conservation and overfishing prevention, with limited attention to climate-driven ocean warming, acidification, and ecosystem change. In a wider marine health context, the Marine Strategy Framework Directive address climate change as a cross-cutting issue, which however is not yet formally integrated in as a driver implementation framework. Development of coherent ocean governance and policies, including climate change, is the subject of the European Ocean pact (European Commission, 2025b).

Dedicated EU policies for the climate resilience of food processing, transport, and retail sectors remain absent. While broader frameworks cover critical infrastructure such as transport and electricity systems, cascading risks across food distribution remain insufficiently assessed. Member States may mobilize the European Solidarity Fund during disasters to support recovery, yet many systemic risks remain unaddressed. The forthcoming European Climate Resilience and Risk Management Initiative may help close this gap by introducing mandatory climate risk assessments across these segments.

EU policies addressing food insecurity for consumers remain limited compared to production-oriented support. For instance, the Fund for European Aid to the Most Deprived (European Commission, 2024), now integrated into ESF+ (ESF+, European Commission, 2021b), provides food aid to 14.2 million vulnerable people. The proposed 2028–2034 framework reinforces this through a 14% social expenditure target for food and material assistance. Food and nutrition security remain strongly shaped by socio-economic conditions, with climate-driven price volatility disproportionately affecting vulnerable groups (European Environment Agency, 2024). While CAP supports producer stability within the EU, reliance on international trade exposes consumer prices to global shocks.

The various strategies and legislative instruments in the EU recognize the necessity of food system approaches to address risks of climate change as well as non-climatic risks. Although these instruments address food system resilience from complementary angles — as shown in Fig. 2 — they do not form a coherent hierarchy. This institutional separation may result in fragmented implementation and weak alignment across policy domains.

For instance, the producer-focused orientation of the Commission's Vision for Agriculture and Food, and its distance from a fully integrated food system approach, has raised concerns that reduced sustainability ambition may undermine long-term resilience (van Zanten et al., 2025; Pe'er et al., 2022, 2020; Mennig, 2024). Comprehensive stress testing of the EU food system (including climate impacts and interactions with non-climate risk drivers) is needed to identify weaknesses and data gaps.

[4] https://climate.ec.europa.eu/eu-action/adaptation-and-resilience-climate-change/european-climate-resilience-and-risk-management-integrated-framework_en?prefLang=en, accessed Sep 30, 2025

Current policy fragmentation and remaining gaps beyond production indicate that Europe is only partially prepared for increasing climate risks, particularly during the ongoing sustainability transition (Peláez et al., 2025; European Environment Agency, 2024; Muro et al., 2025).

Looking forward, for the EU 2028–2034 financial framework, currently proposed reforms include a merged "National and Regional Partnership Fund" covering agriculture, rural development, fisheries, regional development/cohesion, and maritime policies, alongside an 8.7 billion Euros facility for emerging challenges (European Commission, 2025e,d). This reform may provide an opportunity to enhance locally tailored agricultural policies, aligned with broader climate and environmental goals as part of a wider rural resilience framework. However, it is essential that the wider European and global perspectives regarding the collective impacts of these regional policies are systematically considered.

While integrated policy frameworks are essential, the ultimate success depends entirely on moving past strategic institutional design to resolve the concrete bottlenecks of on-the-ground execution.

7. EU policies and practical implementation barriers

Translating high-level policy visions into operational outcomes requires coherent, comprehensive and predictable regulatory frameworks (as discussed in the previous section), while addressing practical implementation barriers. While adaptation measures are widely proposed, on-the-ground uptake depends heavily on financial resources, transition risks, institutional arrangements, social trust, and local fit.

Europe can boost adoption by improving the alignment support, services, and incentives. Stakeholder studies highlight knowledge gaps, funding constraints, system complexity, limited collaboration, and conflicting priorities, alongside a policy focus that favors primary food production over whole-system execution (Turner et al., 2025). Evidence demonstrates that effective interventions require bundled, multi-modal policy strategies rather than stand-alone technical tools or isolated subsidies (Warner et al., 2022). In this context, the proposed European Cohesion and Agriculture Fund (European Commission, 2025e) could address a key bottleneck by providing coordinated and adequately resourced support.

This implementation bottleneck spans all food sectors, though dominant barriers vary (Wreford et al., 2017). In European livestock, fragmented policy support, data limitations, and weak financial incentives leave farmers caught between private costs and public benefits, suppressing the adoption of multifunctional practices (Méité et al., 2024; Alrhmoun et al., 2025). For fisheries and aquaculture, governance and legitimacy gaps dominate; aquaculture remains top-down and technology-driven, while fisheries management lacks formal adaptation mandates and necessary legal–financial infrastructure (Lindegren and Brander, 2018; Reid et al., 2019; Antonio Pérez Agúndez et al., 2025). Downstream processing and transport face comparable hurdles, where high upfront costs, inadequate infrastructure, regulatory incoherence, and organizational inertia impede transformations such as cool-chain adaptation (Fatorachian and Kazemi, 2026). Overcoming these multi-sectoral barriers requires coordinating polycentric governance and bridging institutional disconnects where policy, funding, and execution are managed by separate entities (Wreford et al., 2017; Katic, 2021; de Steenhuijsen Piters et al., 2021).

Ultimately, these gaps reveal that Europe remains only partially prepared for escalating climate risks. Safeguarding food security requires shifting agricultural policies to reward producers for transitioning to climate-proof practices. Instruments like carbon farming illustrate this shift—compensating farmers for ecosystem and stability services that secure long-term food supply (Smith et al., 2020). Because climate-proofing requires agency, buffering capacity, connectivity, and diversity, credible and highly coordinated institutions remain paramount to executing food system adaptation across Europe (de Steenhuijsen Piters et al., 2021).

CRediT authorship contribution statement

Christoph Müller: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Frank Dentener:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Eline Vanuytrecht:** Writing – review & editing, Writing – original draft, Investigation. **Elizabeth J.Z. Robinson:** Writing – review & editing, Writing – original draft. **Maurits van den Berg:** Writing – review & editing, Writing – original draft. **Andrea Toreti:** Writing – review & editing, Writing – original draft. **Willem Maetens:** Writing – review & editing, Writing – original draft. **Shouro Dasgupta:** Writing – review & editing, Writing – original draft. **Frida Lager:** Writing – review & editing, Writing – original draft. **Rui Catarino:** Writing – review & editing, Writing – original draft.

Declaration of competing interest

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

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