The Impact of Climate Change and Sustainability on Food Safety

Food Safety Summit, 2024

Rosemont, IL

May 9, 2024

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Outline

- Definitions
- Examples of Food Safety Impacts
- Potential Implications
- Interplay of Sustainability and Climate Change
- Conclusions

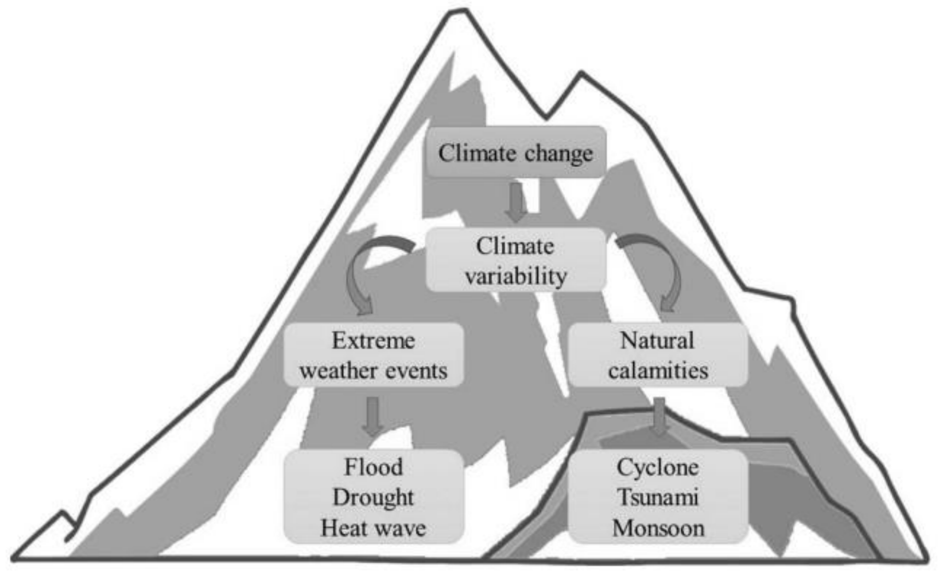


FIGURE 1. *Relationship among climate variability, the effects of climate change, and other related phenomena.*

Models predict mean global warming from 1.5 to 5.88C and a rise in the mean global precipitation of 5 to 15% by 2100

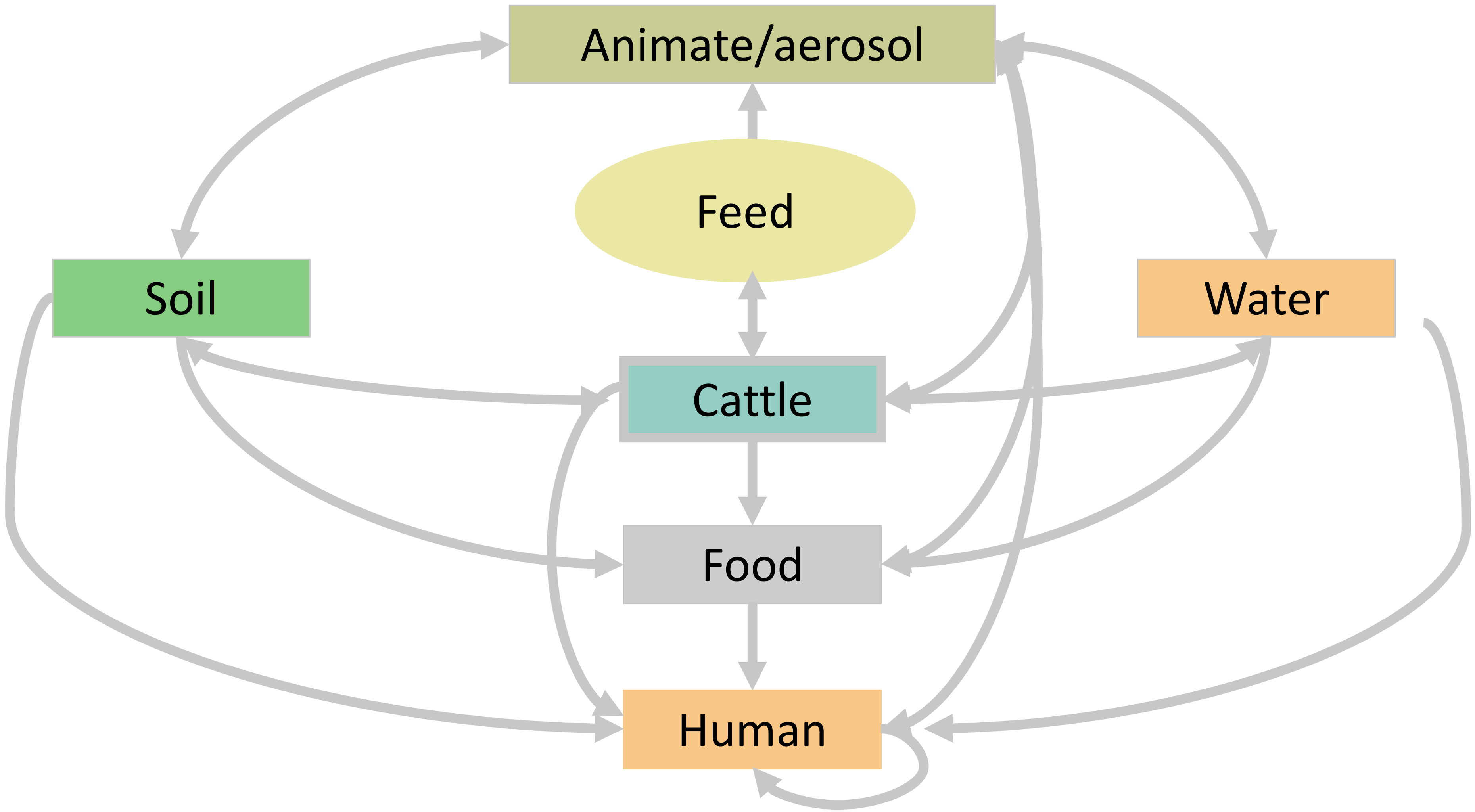
Duchenne-Moutien and Neeto. 2021. J. Food Prot. 84 (11): 1884–1897 https://doi.org/10.4315/JFP-21-141J.

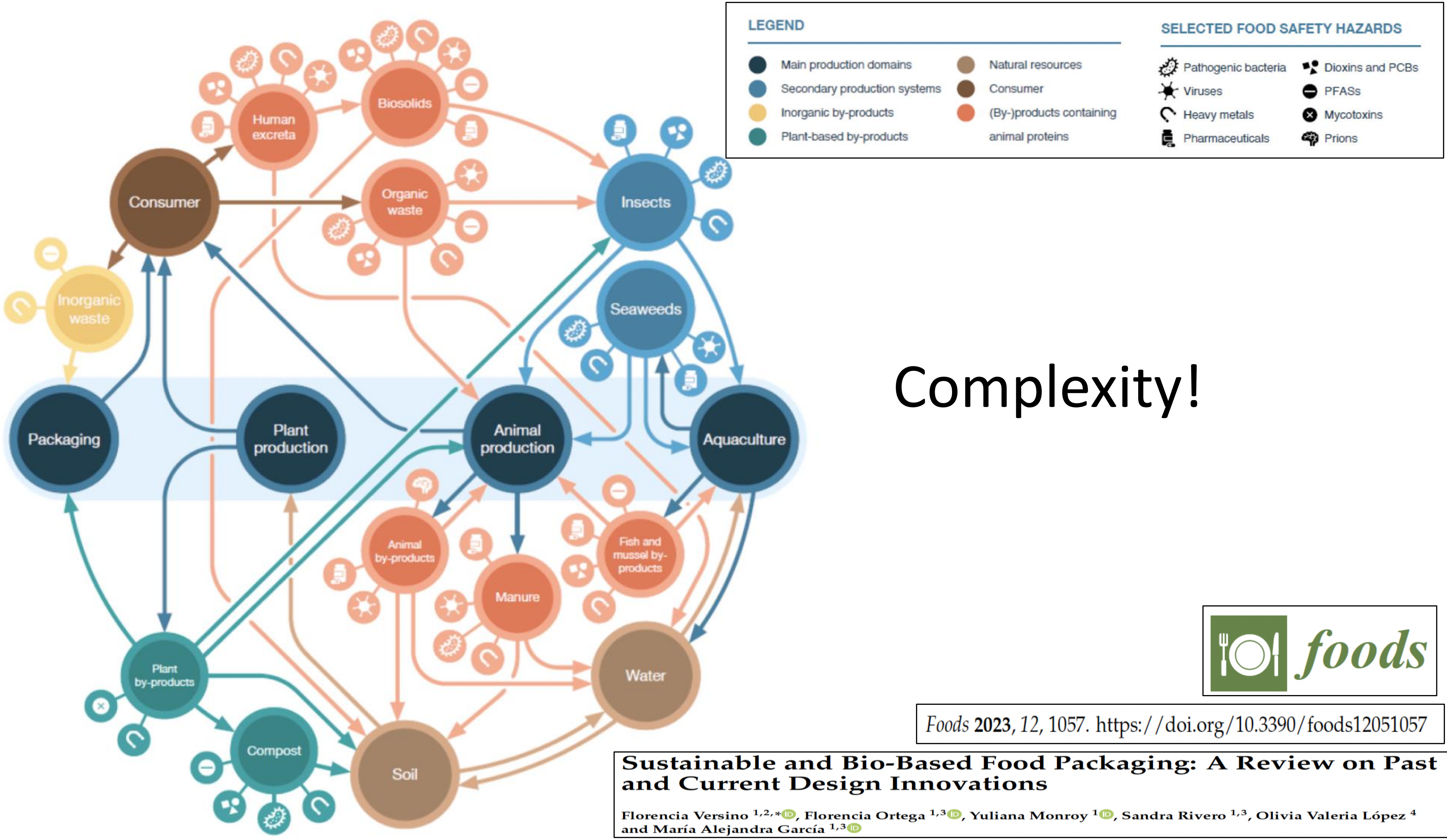
- Global Climate change -- significant variation of average weather conditions over several decades or longer. The longer-term trend differentiates climate change from natural weather variability (World Bank)
- Global warming -- Long-term heating of Earth's surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in Earth's atmosphere (NASA)
- Anthropogenic

Manifestations of Global Climate Change

- Major climatic factors influenced
  - Temperature
  - Relative humidity
  - Precipitation
  - Sunlight (UV)
  - Climate variability (Global "Weirding")
- Increased prevalence of catastrophic weather events
- Changes to:
  - Sea levels and salinity
  - Crop yields
  - Soil quality
  - Nitrogen deposition
  - Plant diversity
  - Animal (including human) and crop diseases

The Critical Role of Water in the Farm-to-Fork Continuum





Complexity!

Foods **2023**, *12*, 1057. https://doi.org/10.3390/foods12051057

Sustainable and Bio-Based Food Packaging: A Review on Past and Current Design Innovations

Florencia Versino [1,2,*], Florencia Ortega [1,3], Yuliana Monroy [1], Sandra Rivero [1,3], Olivia Valeria López [4] and María Alejandra García [1,3]

Food Safety Implications of Global Climate Change

- *Changes in prevalence, occurrence, and distribution; dynamics of growth and survival; and pathogenic potential, of microbial (bacteria, viruses, parasitic protozoa) pathogens in waters and food intended for human and animal consumption*
- **It's all about competition (changing balance)**
- **Examples**
  - *Global expansion of harmful algal blooms and pathogenic Vibrio spp.*
  - *Increased fungal growth with resultant formation of mycotoxins*
  - *Elevated risk for emerging zoonoses*
  - *Potential for increased veterinary drug residues and associated antibiotic resistance of microbes*
  - *Increased pesticide use and associated residues*

Table 1: Key foodborne pathogens currently ranked in Canada to consider in the context climate change (6)

Pathogen	Symptoms (42)	Current cases per 100,000 people (6)	Influence of climate on occurrence (20,43)
Norovirus	Symptoms include nausea, vomiting, diarrhea, stomach cramps, low-grade fever, chills, headache, muscle aches and fatigue	3,223.79	Extreme weather events (such as heavy precipitation and flooding) and decreased air temperature
Clostridium perfringens	Symptoms include diarrhea, pain and cramps, stomach bloating, increased gas, nausea, weight loss, loss of appetite, muscle aches and fatigue. In rare cases, severe dehydration, hospitalization, death	544.50	Uncertain
Campylobacter spp.	Symptoms include fever, nausea, vomiting, stomach pain, and diarrhea. In rare cases, hospitalization and long-lasting health effects, death	447.23	Changes in the timing or length of seasons, increased air temperatures, precipitation and flooding
Salmonella spp., nontyphoidal	Symptoms include chills, fever, nausea, diarrhea, vomiting, stomach cramps, and headache. In rare cases, hospitalization and long-lasting health effects, death	269.26	Changes in the timing or length of seasons, extreme weather events, increased air temperatures
Bacillus cereus	Symptoms include diarrhea or vomiting. In rare cases, hospitalization and long-lasting health effects, death	111.60	Changes in the timing or length of seasons, drought
Verotoxigenic *Escherichia coli* non-O157	Symptoms include diarrhea. In rare cases, hospitalization and long-lasting health effects, death	63.15	Changes in the timing or length of seasons, extreme weather events, increased air temperatures
Verotoxigenic *Escherichia coli* O157	Symptoms include diarrhea. In rare cases, hospitalization and long-lasting health effects, death	39.47	Changes in the timing or length of seasons, extreme weather events, increased air temperatures
Toxoplasma gondii	Symptoms include minimal to mild illness with fever. In rare cases, inflammation of the brain and infection of other organs, birth defects	28.10	Extreme weather events, increased air temperatures, precipitation (44)
Vibrio parahaemolyticus	Symptoms include diarrhea, stomach cramps, nausea, vomiting, fever and headache. In rare cases, liver disease	5.53	Extreme weather events, increased air temperatures, increased sea surface temperature
Listeria monocytogenes	Symptoms include fever, nausea, cramps, diarrhea, vomiting, headache, constipation, muscle aches. In severe cases, stiff neck, confusion, headache, loss of balance, miscarriage, stillbirth, premature delivery, meningitis, death	0.55	Extreme weather events, increased air temperatures, precipitation
Vibrio vulnificus	Symptoms include diarrhea, stomach cramps, nausea, vomiting, fever, headache. In rare cases, liver disease	<0.0	Extreme weather events, increased air temperatures, increased sea surface temperature

Abbreviations: spp., species; <, inferior to
Note: Currently, the five most common foodborne pathogens are noroviru

Suggested citation: Smith BA, Fazil A. How will climate change impact microbial foodborne disease in Canada? Can Commun Dis Rep 2019;45(4):108–13. https://doi.org/10.14745/ccdr.v45i04a05

Shellfish Toxin/*Vibrio* Examples

Landrigan PJ, et al. Human Health and Ocean Pollution. *Annals of Global Health*. 2020; 86(1): 151, 1–64. DOI: https://doi.org/10.5334/aogh.2831

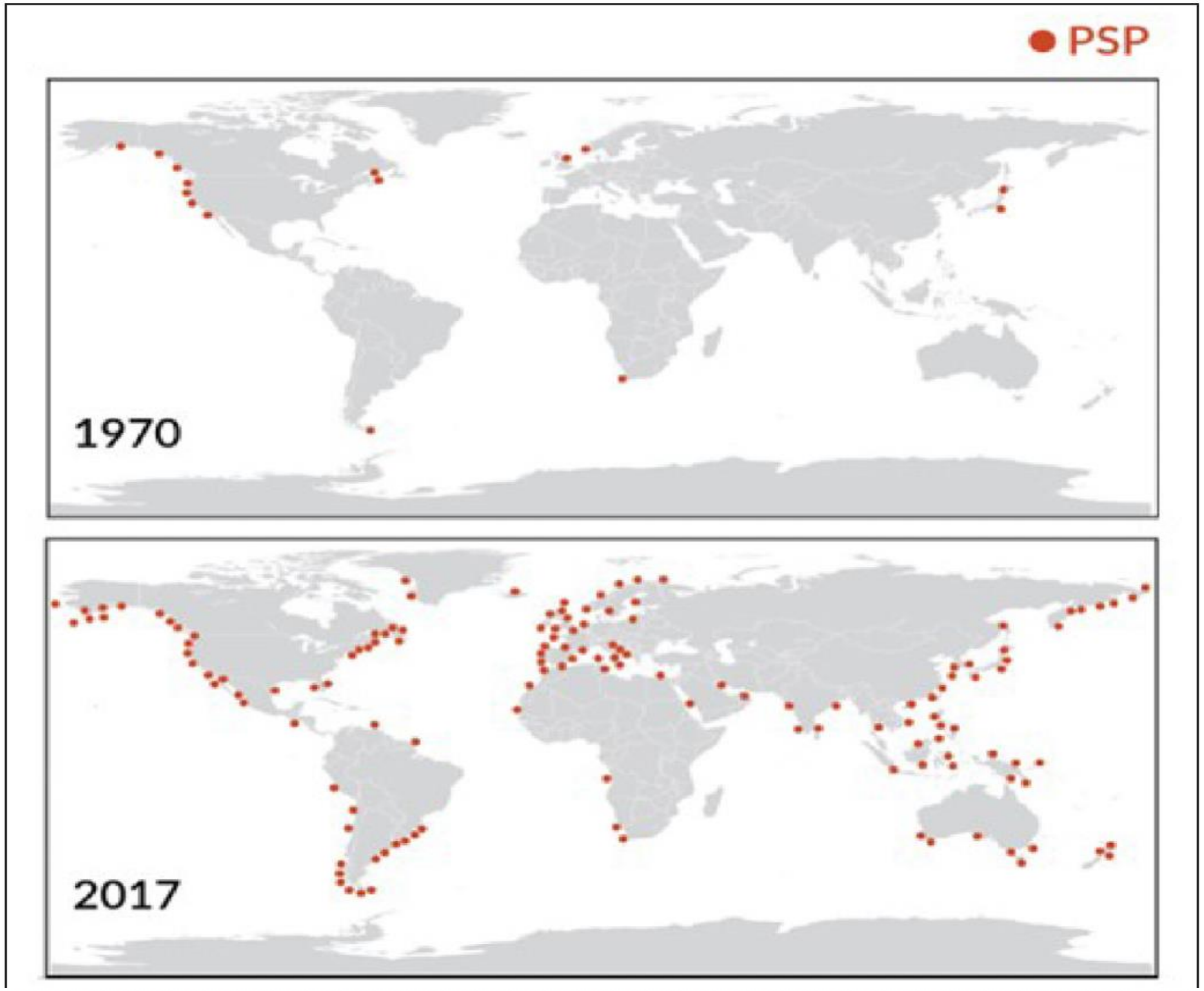


Figure 10: Geographical Distribution of Paralytic Shellfish Poisoning (PSP) Events, 1970 and 2017.
Source: US National Office for HABs, Woods Hole, MA.

TEXT BOX 4: Reduced Water Flow and Increased Frequency of HABs.

An example of an area where changes in freshwater flow may be affecting HAB incidence is in the Bohai Sea of China. The Bohai is one of several regions in China where the number of HABs has increased in recent years. Due to droughts and water diversions for drinking water and agriculture, several of the rivers that used to flow freely into the Bohai are now dry for many days every year. This reduces the dilution of pollution loads in nearshore waters and also reduces stratification.

Dams are another factor that can increase frequency of HABs by altering fresh water flow into the ocean. Dams decrease turbidity and the availability of silicate to downstream waters due to sediment trapping within impounded waters. A decrease in the amount of silicate reaching coastal waters, concurrent with increases in water transparency can lead to shifts in the nutrient ratios that regulate phytoplankton community composition [390]. An increase in HAB frequency has been observed downstream of the massive Three Gorges Dam in China, and this increase is linked to a decrease in sedimentation and turbidity [391].

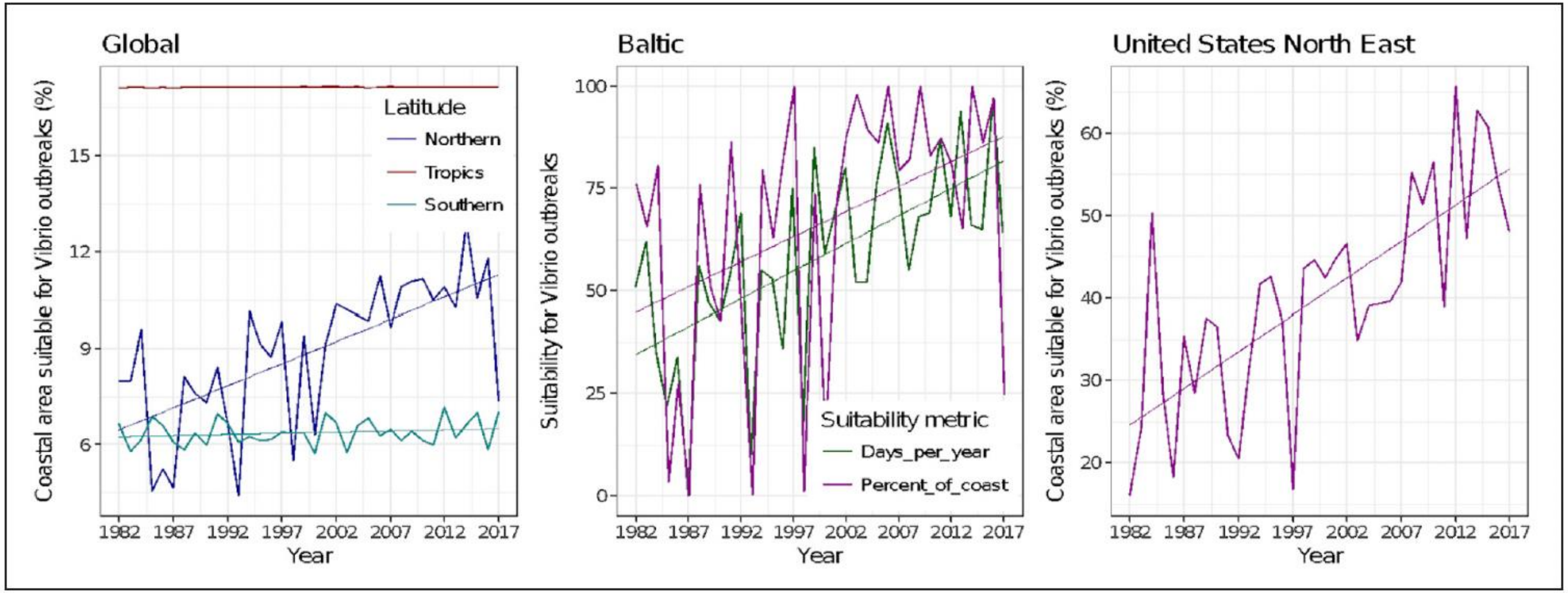


Figure 11: Trends in conditions favorable to *Vibrio* outbreaks in selected world regions [411].
Source: Reprinted from Watts et al. The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. *Lancet* 392: 2479–2514, 2018, with permission from Elsevier.

Landrigan PJ, et al. Human Health and Ocean Pollution. *Annals of Global Health*. 2020; 86(1): 151, 1–64. DOI: https://doi.org/10.5334/aogh.2831

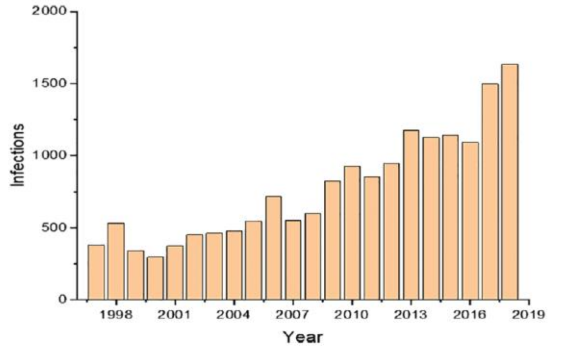


Fig. 2. Annual *Vibrio* (not including toxigenic cholera) infections in the US. Source: Centers for Disease Control (www.data.cdc.gov). [Color figure can be viewed at wileyonlinelibrary.com]

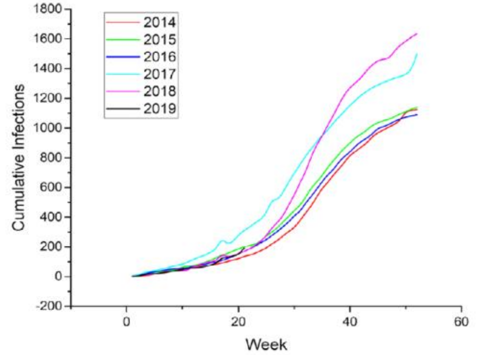


Fig. 4. Cumulative *Vibrio* (excluding toxigenic cholera) infections in the US by week. Year 2019 (black line) is limited by currently available data. Source: Centers for Disease Control (www.data.cdc.gov).

From: Froelich and Daine. 2020. Environmental Microbiology 22(10), 4101–4111. doi:10.1111/1462-2920.14967

Review

Quantitative Modeling of Climate Change Impacts on Mycotoxins in Cereals: A Review

Cheng Liu and H. J. Van der Fels-Klerx *

toxins

Toxins **2021**, *13*, 276. https://doi.org/10.3390/toxins13040276

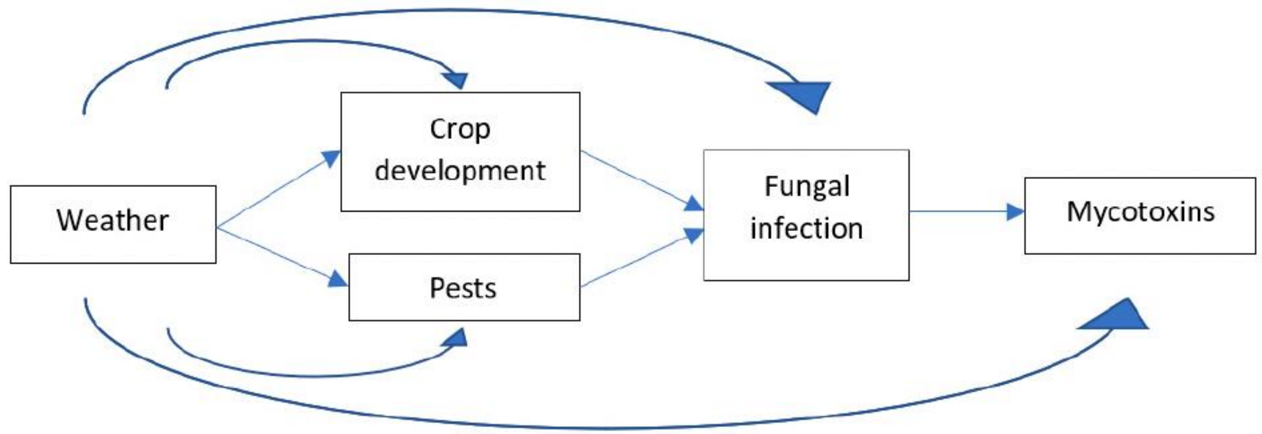
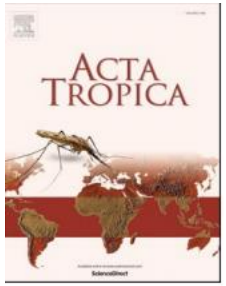


Figure 1. Direct and indirect effects of weather on mycotoxins in cereal grains.

- Variety of mycotoxins
  - Aflatoxins
  - Deoxynivalenol (DON)
  - Nivalenol (NIV)
  - Zearalenone (ZEN)
  - Ochratoxin A
  - Fumonisin
  - Etc.
- Variety of foods
  - Cereal grains
  - Feed grains
  - Commodities (coffee and tea)
  - Milk
  - Etc.

Mycotoxins

- Climate-related influences
  - Depends on mold species
  - Distribution of precipitation (dry and wet conditions)
  - Higher temperatures
  - Atmosphere and soil moisture
  - Catastrophic weather events
  - Changes to growing seasons/production areas
- Impacts likely greater in lower income regions



Climate change and zoonoses: A review of the current status, knowledge gaps, and future trends

Ruwini Rupasinghe [a,*], Bruno B. Chomel [b], Beatriz Martínez-López [a]

Acta Tropica 226 (2022) 106225

https://doi.org/10.1016/j.actatropica.2021.106225

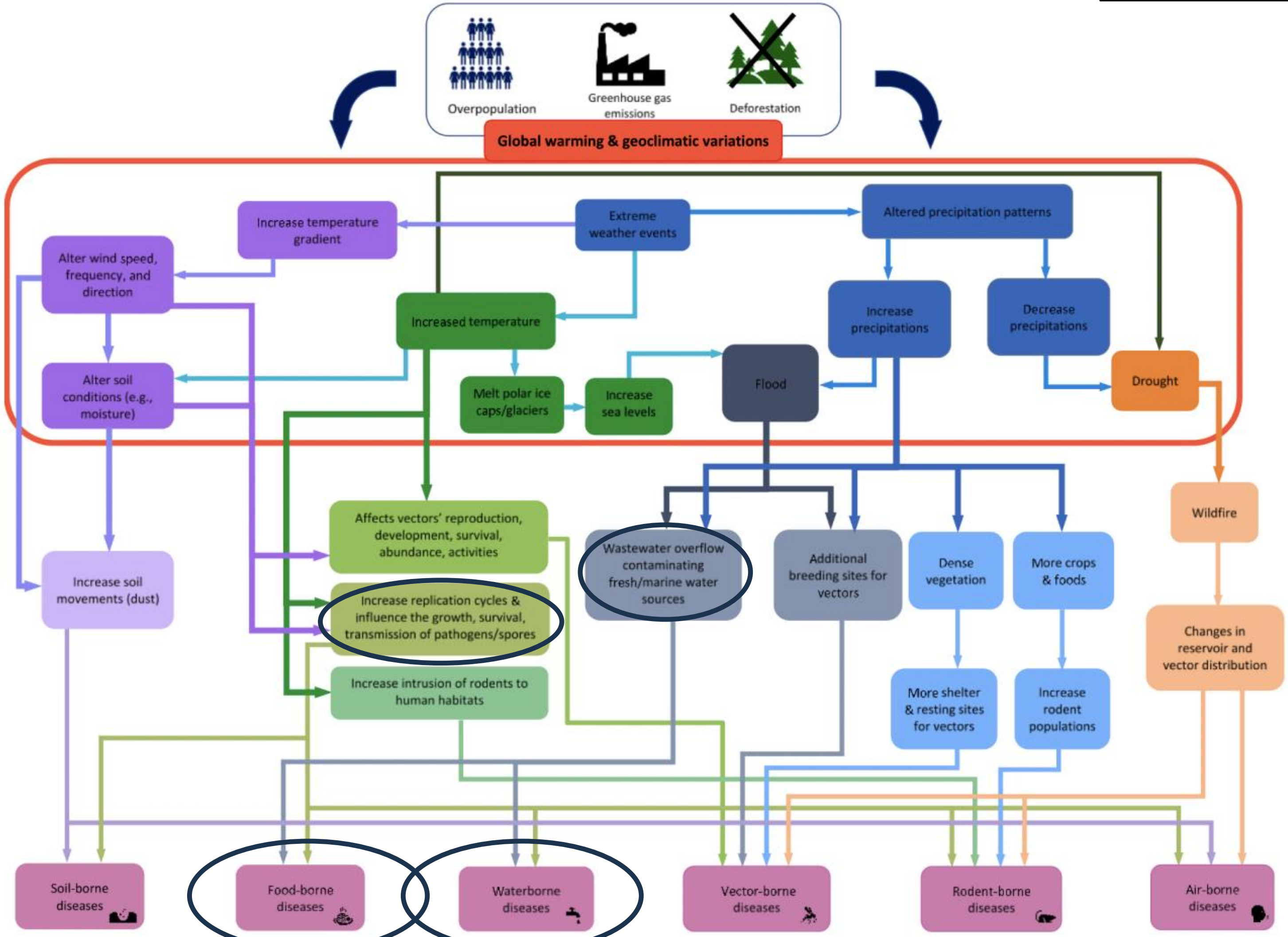
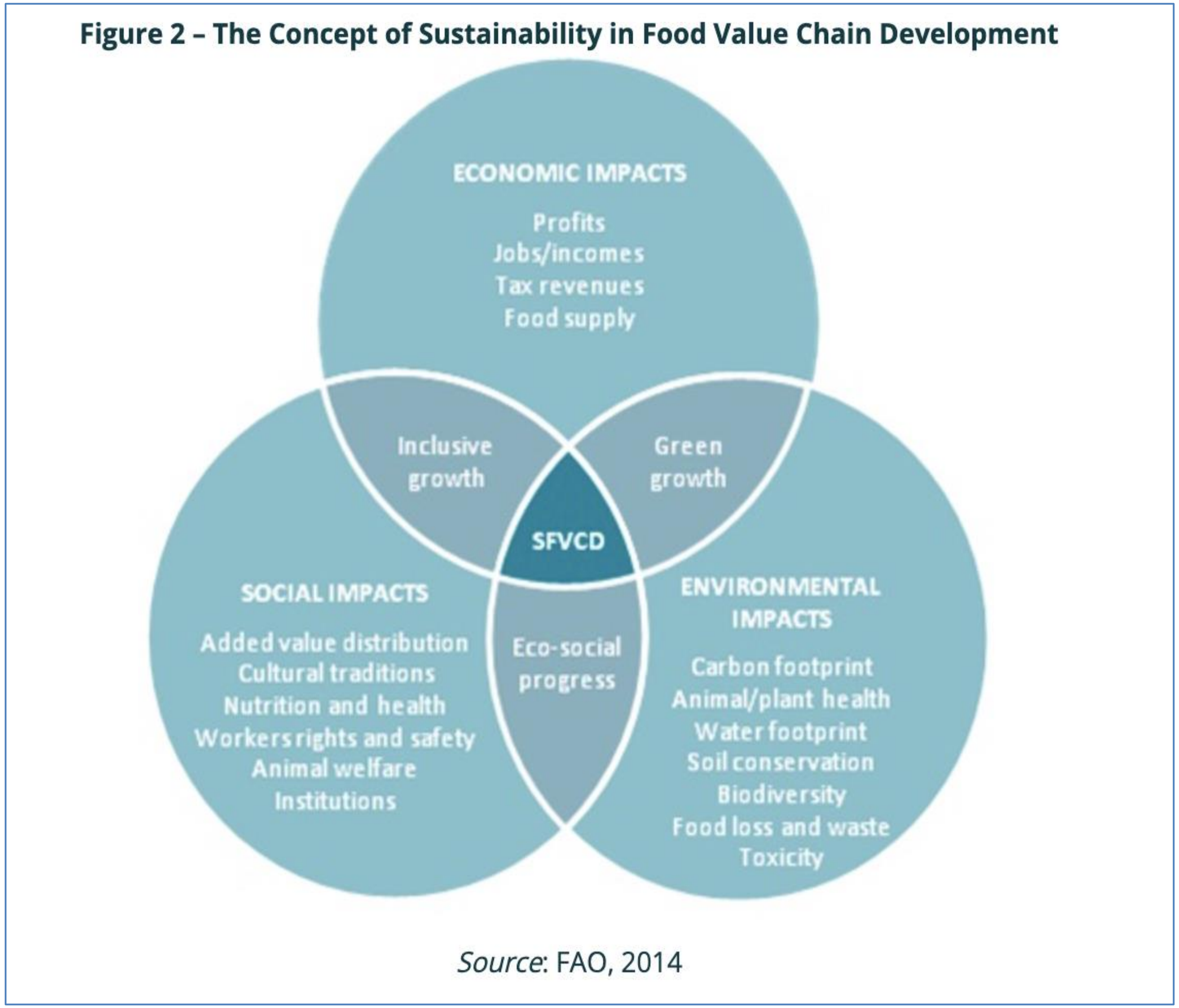


Fig. 1. Impacts of global warming and geoclimatic variations on zoonoses.



From: https://www.fao.org/sustainable-food-value-chains/what-is-it/en/

Sustainability: Fulfilling the needs of current generations without compromising the needs of future generations

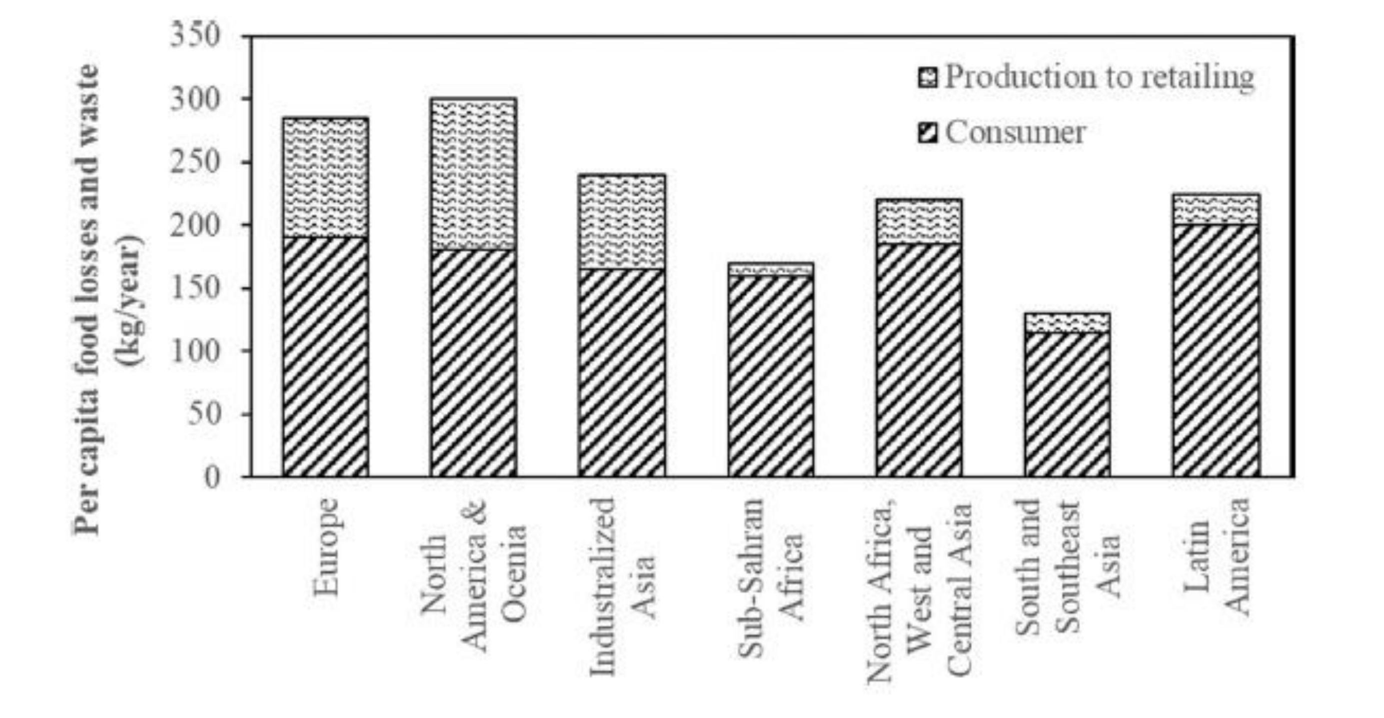
"A ***sustainable*** *food value chain* is a food value chain that:
• is profitable throughout all of its stages (economic sustainability);
• has broad-based benefits for society (social sustainability);
• has a positive or neutral impact on the natural environment (environmental sustainability)"

"A *food value chain* (FVC) consists of all the stakeholders who participate in the coordinated production and value-adding activities that are needed to make food products."

New insights in food security and environmental sustainability through waste food management

Nazrana Rafique Wani[1] · Rauoof Ahmad Rather[2] · Aiman Farooq[1] · Shahid Ahmad Padder[3] · Tawseef Rehman Baba[4] · Sanjeev Sharma[5] · Nabisab Mujawar Mubarak[8] · Afzal Husain Khan[6] · Pardeep Singh[7] · Shoukat Ara[2]

Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-023-26462-y



Food waste is any substance or object which the holder discards or intends to or is required to discard

Circular economy is a system based on the reuse and regeneration of materials or products, especially as a means of continuing production in a sustainable or environmentally friendly manner.

foods

Conflicting Issues of Sustainable Consumption and Food Safety: Risky Consumer Behaviors in Reducing Food Waste and Plastic Packaging

Gyula Kasza [1,2], Nina Veflen [3,4], Joachim Scholderer [5], Lars Münter [6], László Fekete [7], Eszter Zita Csenki [1], Annamária Dorkó [1], Dávid Szakos [2] and Tekla Izsó [1,*]

Foods **2022**, *11*, 3520. https://doi.org/10.3390/foods11213520

Table 1. Messages targeting risky behaviors * from the domain of sustainability–safety controversy regarding food waste.

Risky Consumer Behavior in Food-Waste Mitigation	Examples of Seemingly Controversial Food-Safety Advice	Recommendations to Disband Conflicts between Food Safety and Food-Waste Reduction
Consuming food after use-by date based on sensory evaluation	Respect use-by dates [63]. When in doubt, throw it out [64]. Don't trust your senses [65].	Plan menus ahead of time. Check the labeling during the shopping. Follow the "first in, first out" practice. Differentiate expiration-date types. Keep track of your food stock.
Using a reusable bag many times in a row without washing or sanitizing [106]	Use single-use plastic bags for temporary storage or transportation of RTE (ready-to-eat) food to prevent cross-contamination [37].	Bring your reusable bags to the shop, but pay attention to their proper washing and sanitization (if possible, wash at 60 °C and iron). Wash and sanitize reusable bags dedicated to RTE food after each use. For the industry: Include washing instructions on a label inside each bag.

Foods **2023**, *12*, 1057. https://doi.org/10.3390/foods12051057

Sustainable and Bio-Based Food Packaging: A Review on Past and Current Design Innovations

Florencia Versino [1,2,*], Florencia Ortega [1,3], Yuliana Monroy [1], Sandra Rivero [1,3], Olivia Valeria López [4] and María Alejandra García [1,3]

Among the most significant opportunities for decreasing food waste and enhancing food security are using sensors and intelligent packaging

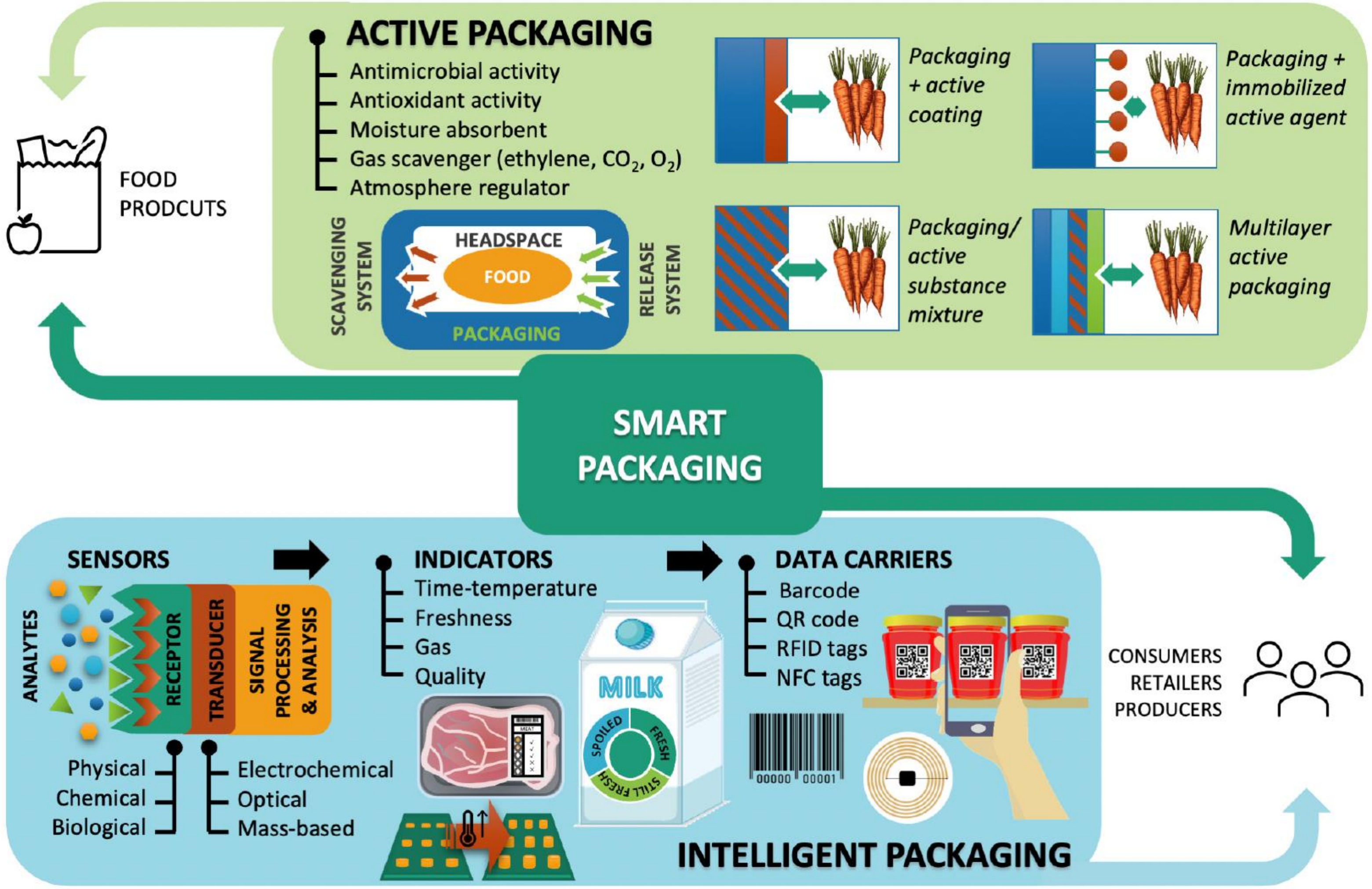
Sensor categories:

--Freshness sensors

--Gas sensors for food package integrity--

--Identification tags like radio-frequency identification tags

--Time–temperature indicators (TTI)



Applications of green technologies-based approaches for food safety enhancement: A comprehensive review

Fakhar Islam[1] | Farhan Saeed[1] | Muhammad Afzaal[1] | Aftab Ahmad[2] | Muzzamal Hussain[1] | Muhammad Armghan Khalid[1] | Shamaail A. Saewan[3] | Ashraf O. Khashroum[4]

Food Sci Nutr. 2022;10:2855–2867.

DOI: 10.1002/fsn3.2915

Abstract

Food is the basic necessity for life that always motivated man for its preservation and making it available for an extended period. Food scientists always tried to preserve it with minimum deterioration in quality by employing and investigating innovative preservation techniques. The food sector always remained in search of eco-friendly and sustainable solutions to tackle food safety challenges. Green technologies (ozone, pulsed electric field, ohmic heating, photosensitization, ultraviolet radiations, high-pressure processing, ultrasonic, nanotechnology) are in high demand owing to their eco-friendly, rapid, efficient, and effective nature in controlling microbes with a negligible residual impact on food quality during processing. The use of green technologies would be a desirable substitute for conventionally available preservation techniques. This paper discusses different food preservation techniques with special reference to green technologies to minimize the deleterious impact on the environment and employs these innovative technologies to play role in enhancing the food safety.

Alternative Protein Sources

- Cultured Meat
  - Microbes derived from use of bovine serum in culture medium; must be free of bovine-specific pathogens, e.g., bovine diarrheal viruses and including infectious prions
- Plant-Based Meat
  - Can carry pathogenic bacteria originating from the raw ingredients, although all but endospore-forming bacteria (e.g., *Clostridium* spp. or *Bacillus* spp.) should be inactivated by heat produced in extrusion
  - Allergens and ‘anti-nutrients’
- Insect Protein
  - Pathogenic microorganisms in edible insects have been reported [bacteria (e.g., *Cronobacter*, *Bacillus, Staphylococcus, Clostridium* spp.; parasitic protozoa (e.g., *Cryptosporidium* spp.), and mycotoxin-producing molds]
- Microbial biomass proteins
  - Largely unknown

Comprehensive REVIEWS in Food Science and Food Safety

Food safety considerations and research priorities for the cultured meat and seafood industry

Kimberly J. Ong[1] | Jeremiah Johnston[2] | Dwayne Holmes[4] | Jo Anne Shatkin[1] | Isha Datar[2] | Vincent Sewalt[3]

Compr Rev Food Sci Food Saf. 2021;20:5421–5448.

DOI: 10.1111/1541-4337.12853

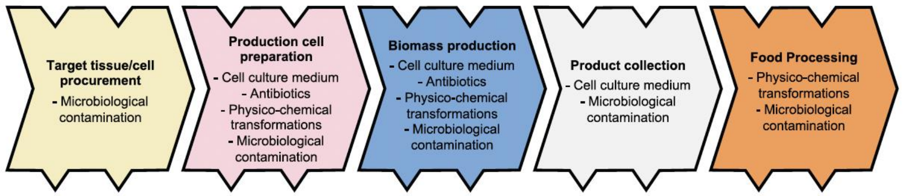
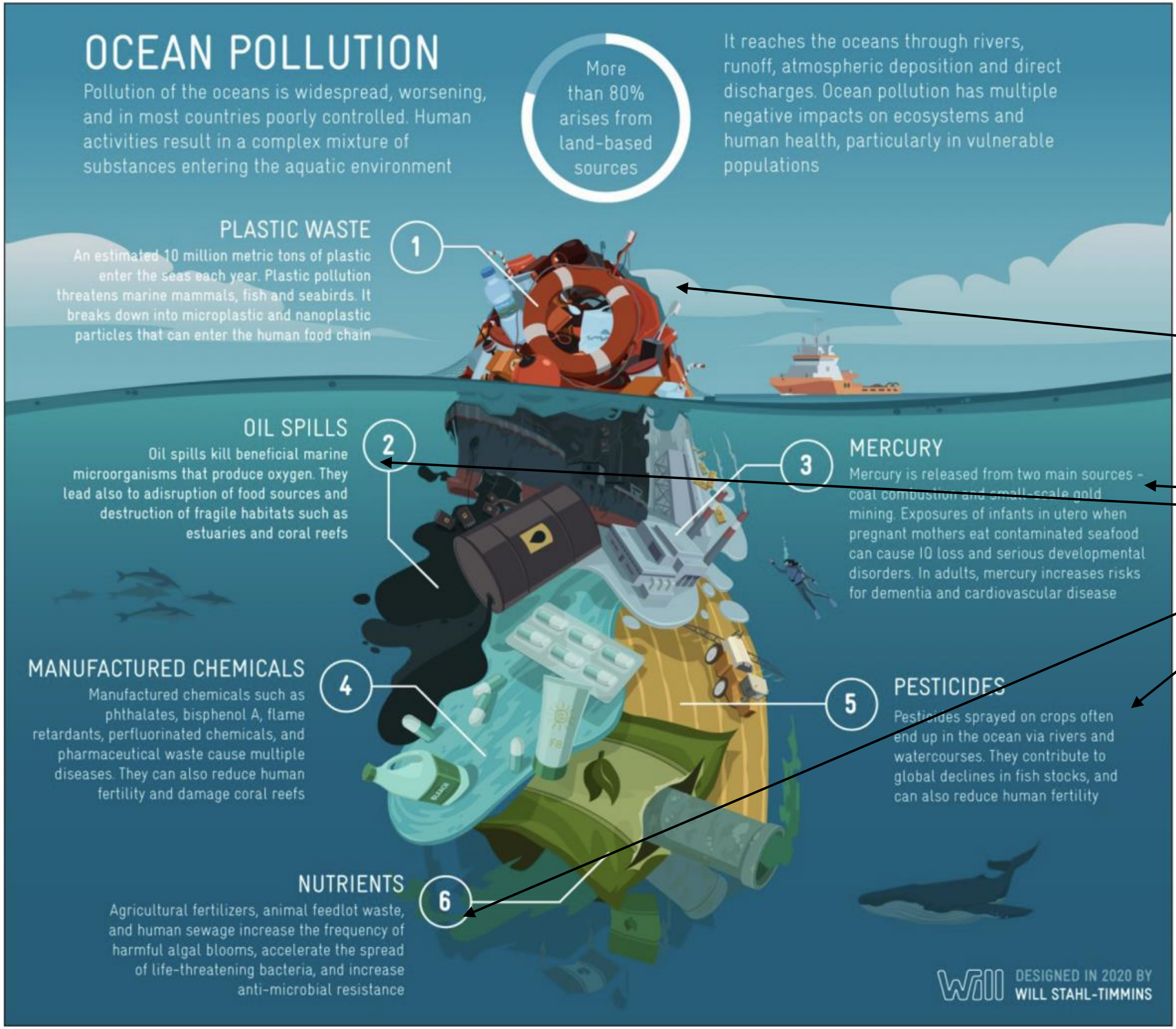


TABLE 1 Summary of source, main potential hazards, and potential outcomes that may require investigation

Source	Main potential hazard(s)	Potential outcomes
Source animal	Bacteria, viruses, parasites, prionsAntibiotics	Introduction of infectious disease agents into cell culture.Increase in antibiotic resistance.
Cell culture medium	Fetal Bovine Growth serum and animal-derived components Antibiotics Inputs at higher concentrations than found in conventional meat or seafoodNovel inputs and allergens	Introduction of infectious disease agents into cell culture from cell culture components. Increase in antibiotic resistance. Could be hazardous to human health (e.g., certain growth factors). Could be hazardous to human health.Potential allergenicity.
Cell storage inputs	Cryoprotectants	Final product contains cryoprotectants in amounts not safe for human consumption.
Cell storage conditions	Leakage of cryopreservation fluid into cells	Microbiological contamination or cross-contamination of cells.
Continual subculturing, handling, and transferring of cells	Microbiological contaminationPhysicochemical transformations	Introduction of infectious disease agents into cell culture. Changes in cell morphology, function, and physiology may result in a final product that has characteristics different to those of conventional meat.
Novel expression products	Hazardous or allergenic proteins or bioactive moleculesIntroduction of traits of concern	Alterations in the types and levels of endogenous gene expression or as a result of genetic drift may cause pleiotropic effects or novel expression products that may not be safe for consumption. May result in traits of concern, such as antibiotic resistance.
Scaffold and microcarriers	Hazardous materials	Materials used for adherent surfaces and their degradation products may not be safe for consumption.
Dissociation reagents	Hazardous reagents	Use of hazardous reagents may end up in the final products.
Food processing	Physicochemical transformationsNovel inputs and allergens	Induction of structural and chemical changes different from those of conventional meat. Could be hazardous to human health.Potential allergenicity.
Equipment, supplies, packaging, cleaning products	Chemicals Microbiological contaminationAllergens	Leaching of hazardous chemicals or substances into cell culture. Introduction of infectious disease agents into cell culture. Cross-contamination with allergenic substances.



Collision of Climate Change and Sustainability
The Big Picture--Oceans

Sustainability

Plastics as packaging materials

Climate Change

Implications of fossil fuel use

Run-off due to increased rainfall and/or flooding

Often impacts reflect both concepts

Landrigan PJ, et al. Human Health and Ocean Pollution. *Annals of Global Health*. 2020; 86(1): 151, 1–64. DOI: https://doi.org/10.5334/aogh.2831

Collision of Climate Change and Sustainability on Food Safety--Conclusions

- Changing food safety risks
- Increased prevalence or risk of known food safety hazards
- Altering the balance or prioritization of food safety risks
- Promoting emergence of new or unforeseen food safety risks
- Introduction of new products for which food safety risks are unknown
- Making it more difficult to manage food safety risks
- Changing how we might manage food safety risks
- Other as yet unknown….

Thank You
Questions?

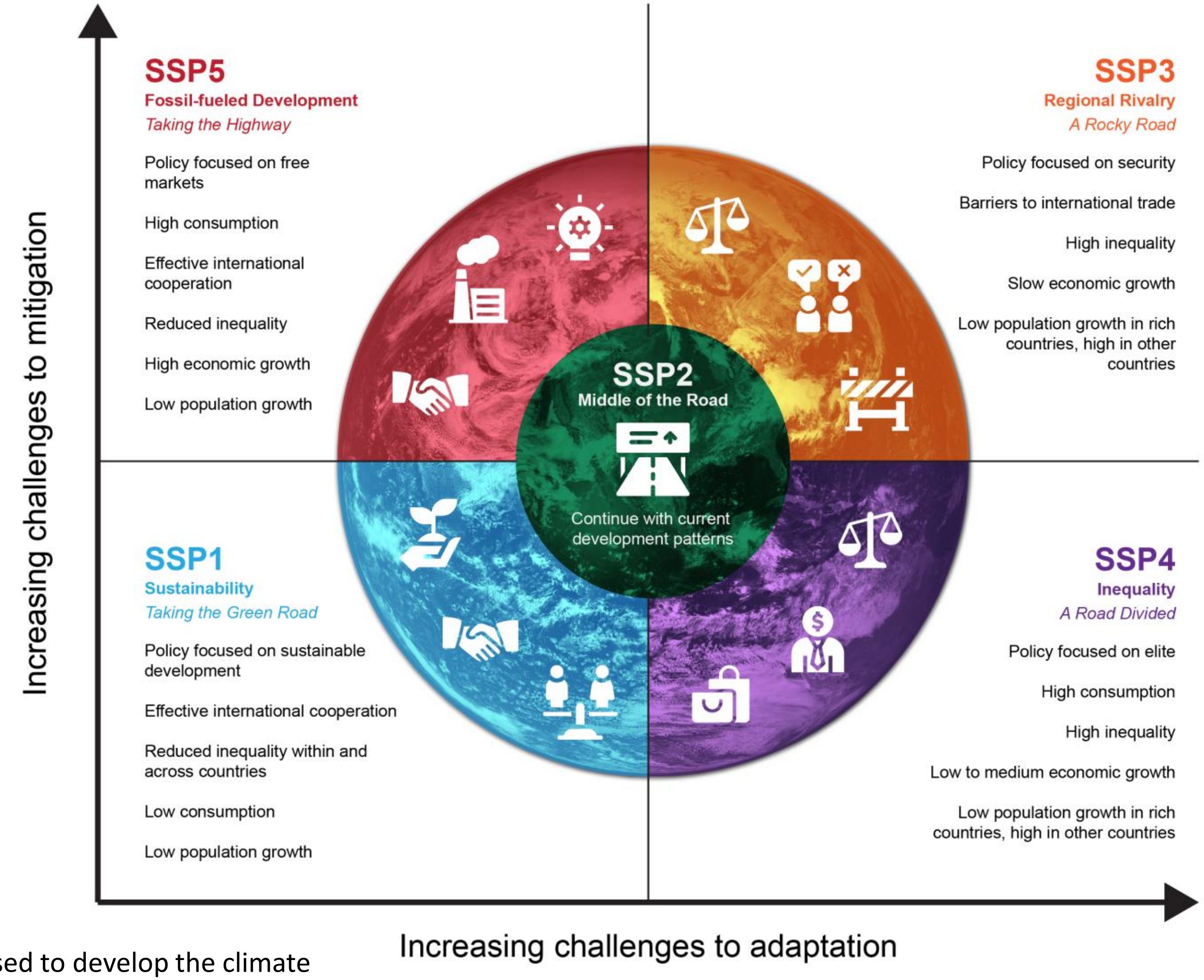
Climate Scenarios and the Challenges and Opportunities they pose to Food Safety and Sustainability

Alison Grantham, Ph.D.

Questions to Tackle Today

- What are climate scenarios?
- How may future scenarios (emissions and socioeconomic pathways) challenge food safety? Food system sustainability?
- Which mitigation strategies or tactics pose the fewest tradeoffs or better yet improve both food safety and sustainability outcomes?

What are Climate Scenarios?



source

Shared socioeconomic pathways (SSPs) are the scenarios used to develop the climate projections (CMIP6) used in the IPCC AR6. Unlike the RCPs, which were used in CMIP5 and were based on GHG concentrations alone, SSPs 'represent changes in [policy], population, economic growth, education, urbanization, and the rate of technological development that would affect future greenhouse gas emissions, *providing a storyline of how we could reach certain levels of warming*.' [source]

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Food System Parameters and Outcomes Vary Widely across Scenarios

Global Environmental Change 22 (2012) 189–209

Contents lists available at SciVerse ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

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Trading more food: Implications for land use, greenhouse gas emissions, and the food system

Christoph Schmitz[a,b,*], Anne Biewald[a], Hermann Lotze-Campen[a], Alexander Popp[a], Jan Philipp Dietrich[a,c], Benjamin Bodirsky[a,d], Michael Krause[a,b], Isabelle Weindl[a]

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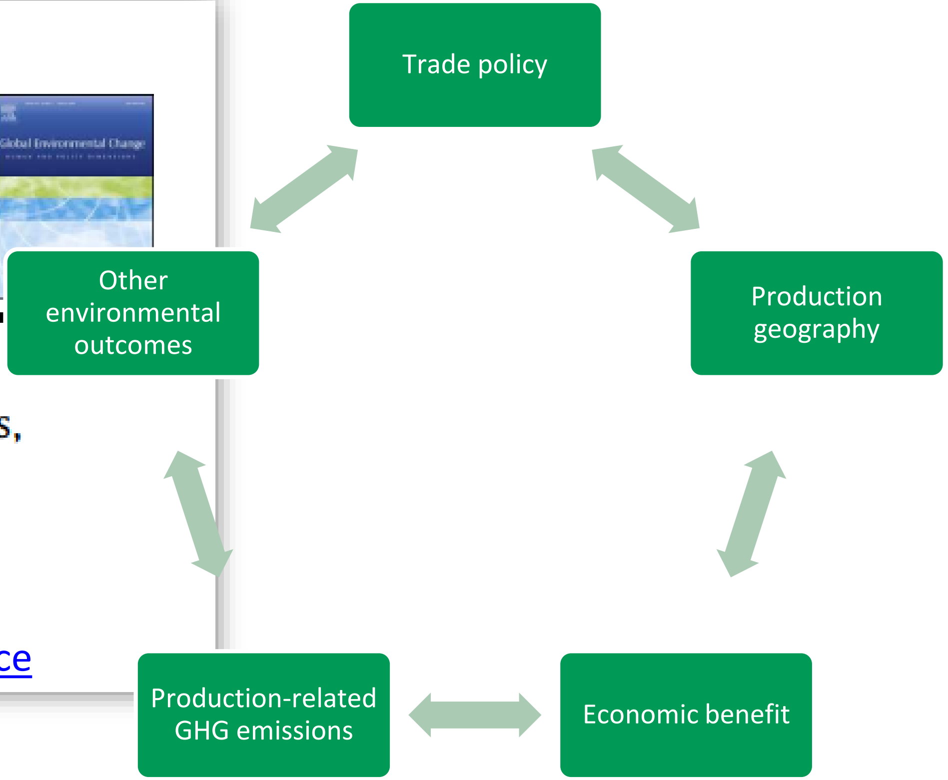

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This Early (ca. 2012) Scenario Analysis found trade liberalization leads to higher economic benefits at the *expense of environment and climate*

Global Environmental Change 22 (2012) 189–209

Contents lists available at SciVerse ScienceDirect

Global Environmental Change

journal homepage: www.elsevier.com/locate/gloenvcha

ELSEVIER

Trading more food: Implications for land use, greenhouse gas emissions, and the food system

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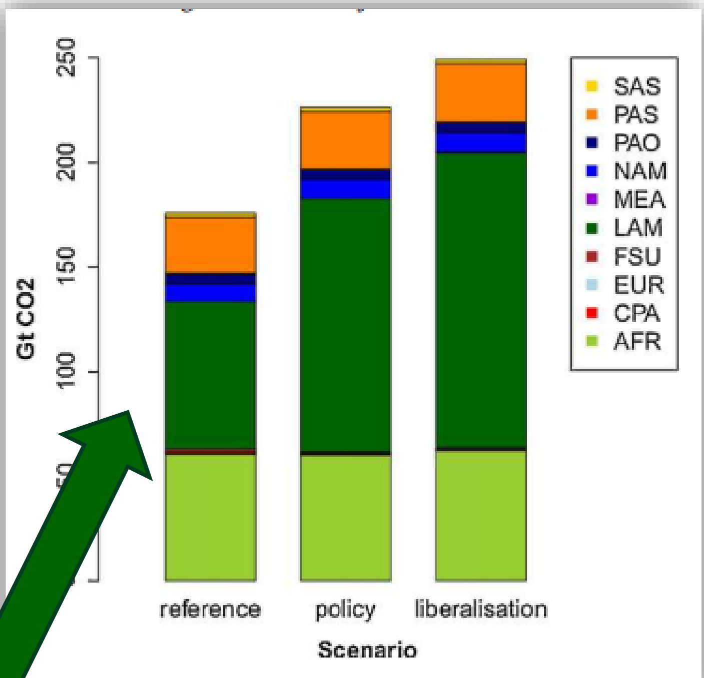

ig. 9. CO_2 emissions from deforestation in three trade scenarios (2005–2045).

Most of these environmental and climate expenses derive from the policy-driven shifts in crop production geography to Latin America and related deforestation.

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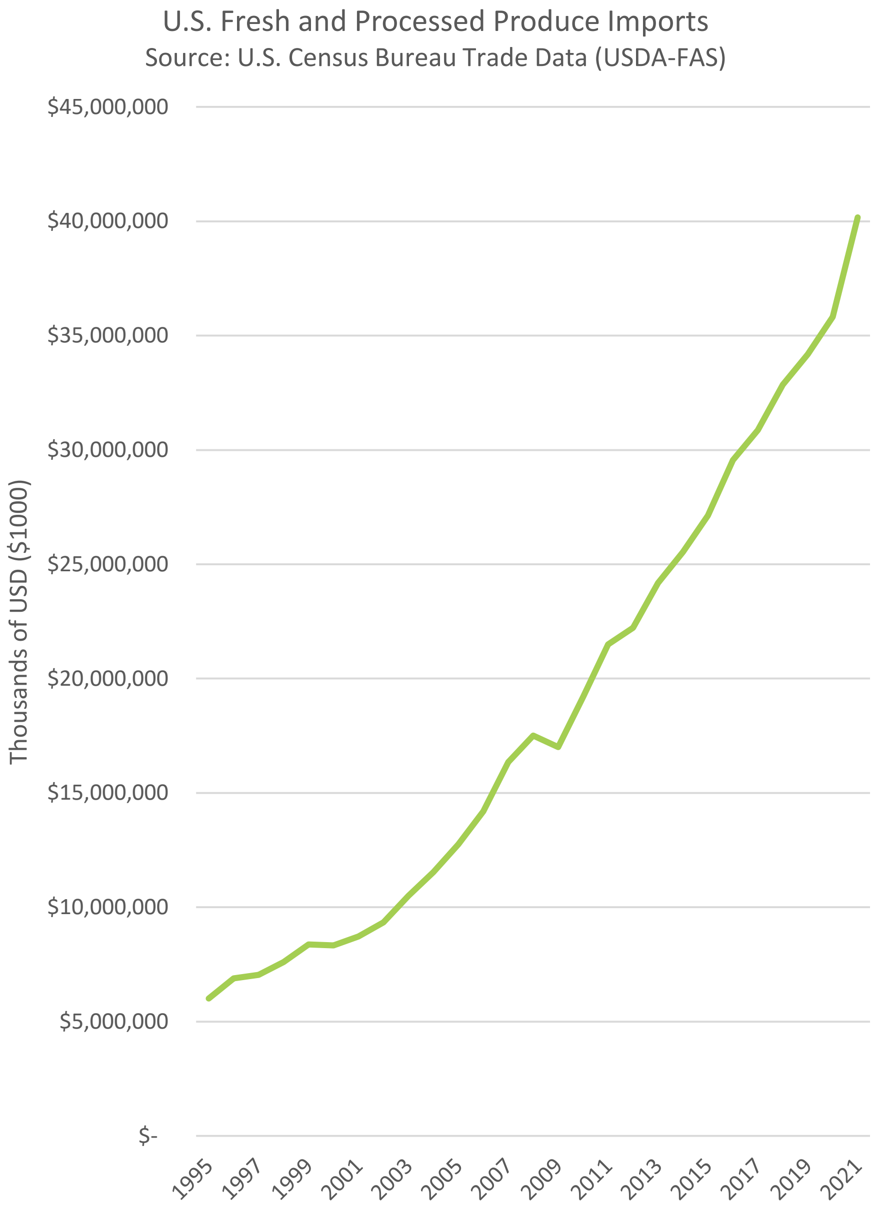
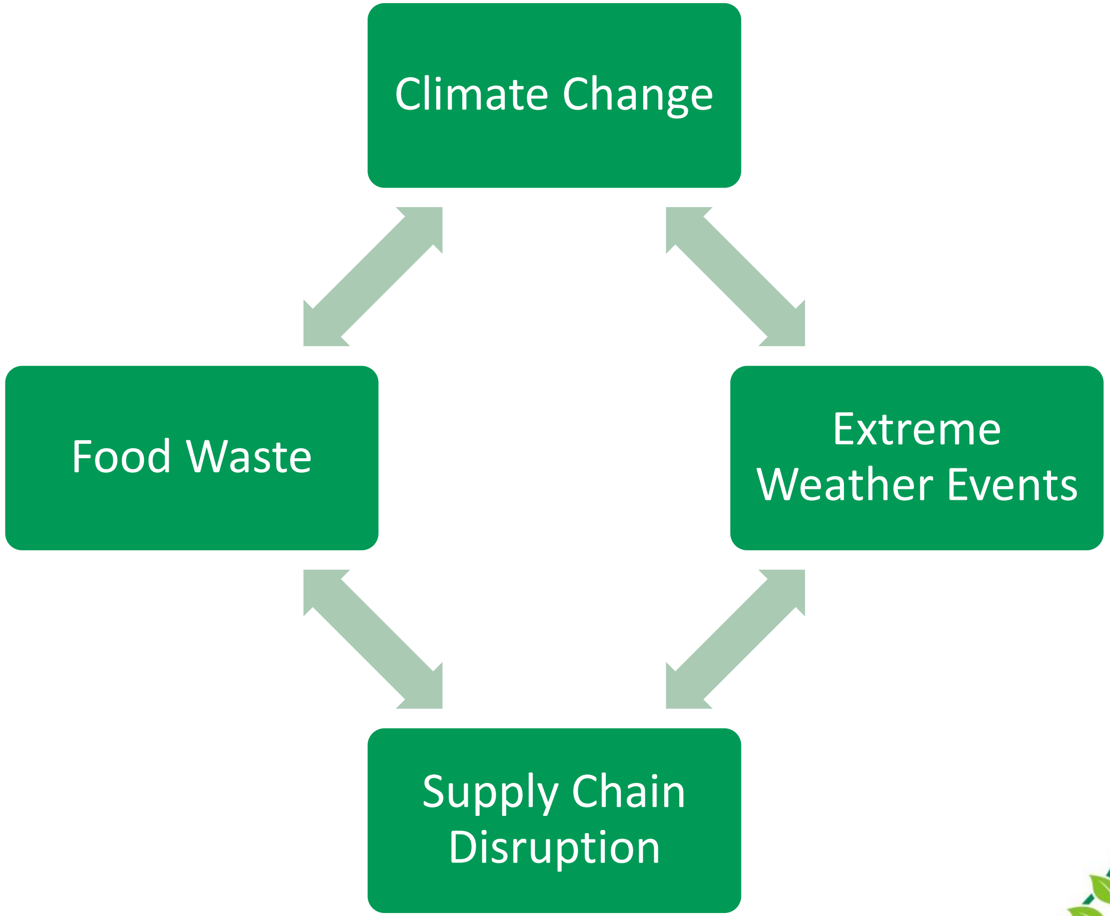
Shifting production into Latin America presents new food safety challenges

- Even in the absence of climate change, pathogen concerns differ in Latin America from the concerns in historic production regions, causing new pathogens of concern to emerge as populations shift to consuming mostly imported produce (e.g., *Cyclospora cayetanensis*) [source]
- Compounding these risk factors are climate change-related increases in weather extremes like rainfall, heat, and drought, each of which have been found to increase prevalence of *Cyclospora* [source]



In addition to impacting pathogen risk, climate scenarios also reveal other important interactions and feedbacks



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Environmental Research
Volume 216, Part 3, 1 January 2023, 114674

The influence of climate change on food production and food safety ☆

Isidro Juan Mirón [a], Cristina Linares [b], Julio Díaz [b]

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Highlights

- Climate change is producing and will continue to produce a decrease in crop quality and yields.
- Extreme weather events produce direct effects on animal well-being and thus lower production of animal-origin foods.
- Fishing resources are particularly sensitive to climate change.
- Increasing average global temperatures produce a greater potential risk of food-borne diseases.
- Climate change threatens food security and food safety.

source

"According to the majority of published studies, climate change is producing and will continue to produce a decrease in crop yields, *especially in warm and tropical regions*, with particularly important effects in developing countries, where the capacity to adapt to change is more limited. Not only are yields being affected, the quality of crops is also affected…"

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Environmental Research
Volume 216, Part 3, 1 January 2023, 114674

The influence of climate change on food production and food safety ☆

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Highlights

- Climate change is producing and will continue to produce a decrease in crop quality and yields.
- Extreme weather events produce direct effects on animal well-being and thus lower production of animal-origin foods.
- Fishing resources are particularly sensitive to climate change.
- Increasing average global temperatures produce a greater potential risk of food-borne diseases.
- Climate change threatens food security and food safety.

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"Increasing average global temperatures produce a greater potential risk of food-borne diseases."

"An increase in average temperatures could lead to an **increased risk of proliferation of micro-organisms** that produce food-borne illnesses, such as salmonella and campylobacter. However, in developed countries with information systems that document the occurrence of these diseases over time, *no clear trend has been determined*, in part because of ***extensive food conservation controls***."

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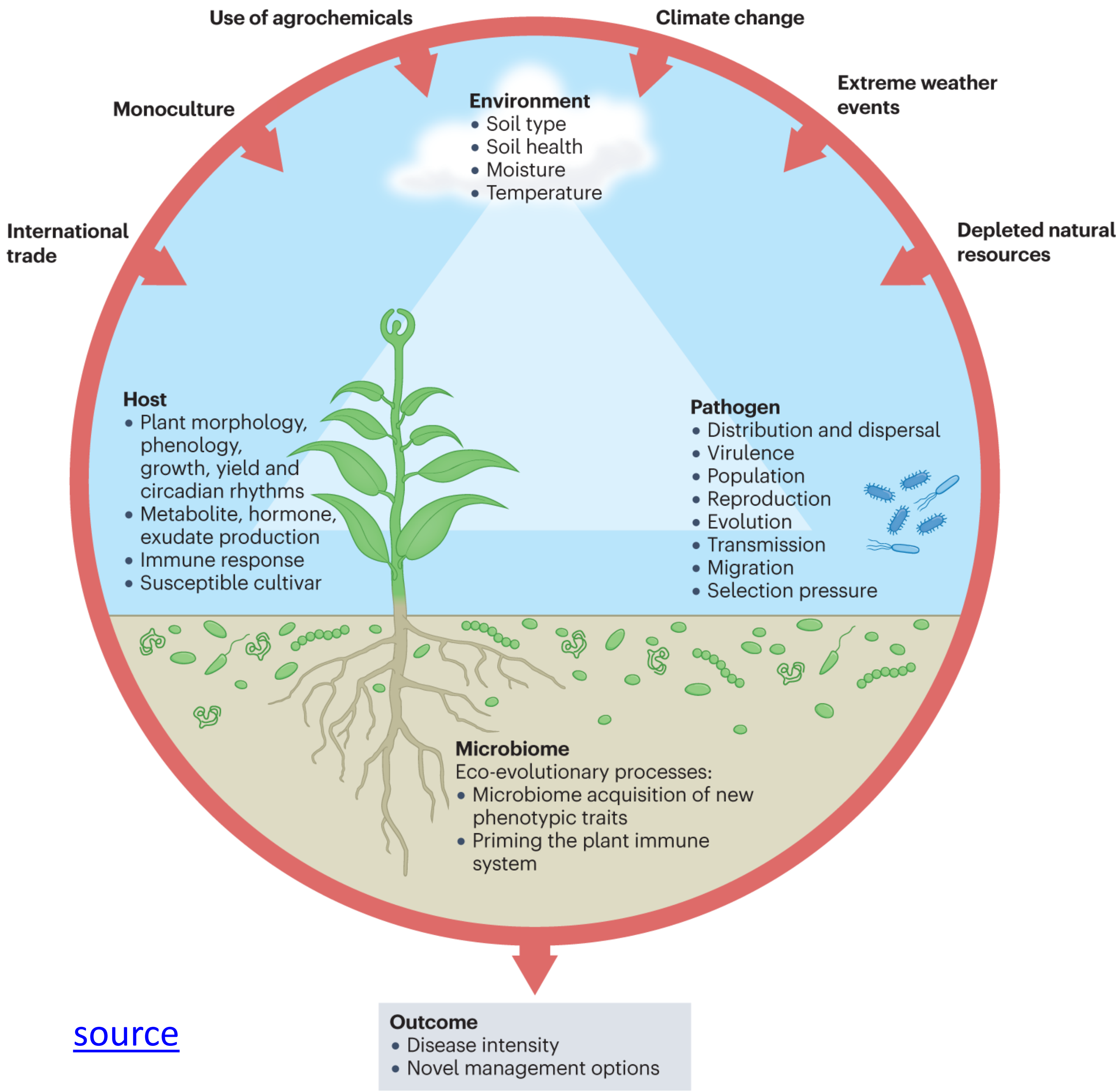

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3 Suggested Mitigation Strategies:

1. Approaches that harness ecological and evolutionary interactions and other nature-based methods can provide future effective tools.
2. "A transdisciplinary approach to understand pathogen biology and ecology from molecular to global scales … Integrating available pathogen biology data with transport, trade, climate and geography can improve monitoring and predictive power of disease incidence...Further boost with biochemical sensors, permanent observatories (airborne signals and vectors), satellite and remote sensing tools, artificial intelligence and the involvement of farmers and other volunteers to get an early report of disease"
3. A global approach, such as the recently proposed global surveillance system138, is urgently needed to continuously monitor and predict global hot spots of important plant diseases, and their socio-economic impacts.

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Scenarios also point to the need for adaptive responses to manage emerging risks

Article | Published: 09 August 2021

Extreme climate events increase risk of global food insecurity and adaptation needs

Tomoko Hasegawa, Gen Sakurai, Shinichiro Fujimori, Kiyoshi Takahashi, Yasuaki Hijioka & Toshihiko Masui

Nature Food **2**, 587–595 (2021) | Cite this article

Abstract

Climate change is expected to increase the frequency, intensity and spatial extent of extreme climate events, and thus is a key concern for food production. However, food insecurity is usually analysed under a mean climate change state. Here we combine crop modelling and climate scenarios to estimate the effects of extreme climate events on future food insecurity. Relative to median-level climate change, we find that an additional 20–36% and 11–33%

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Better-targeted food reserves and other adaptation measures could help fill the consumption gap in the face of extreme climate variability.

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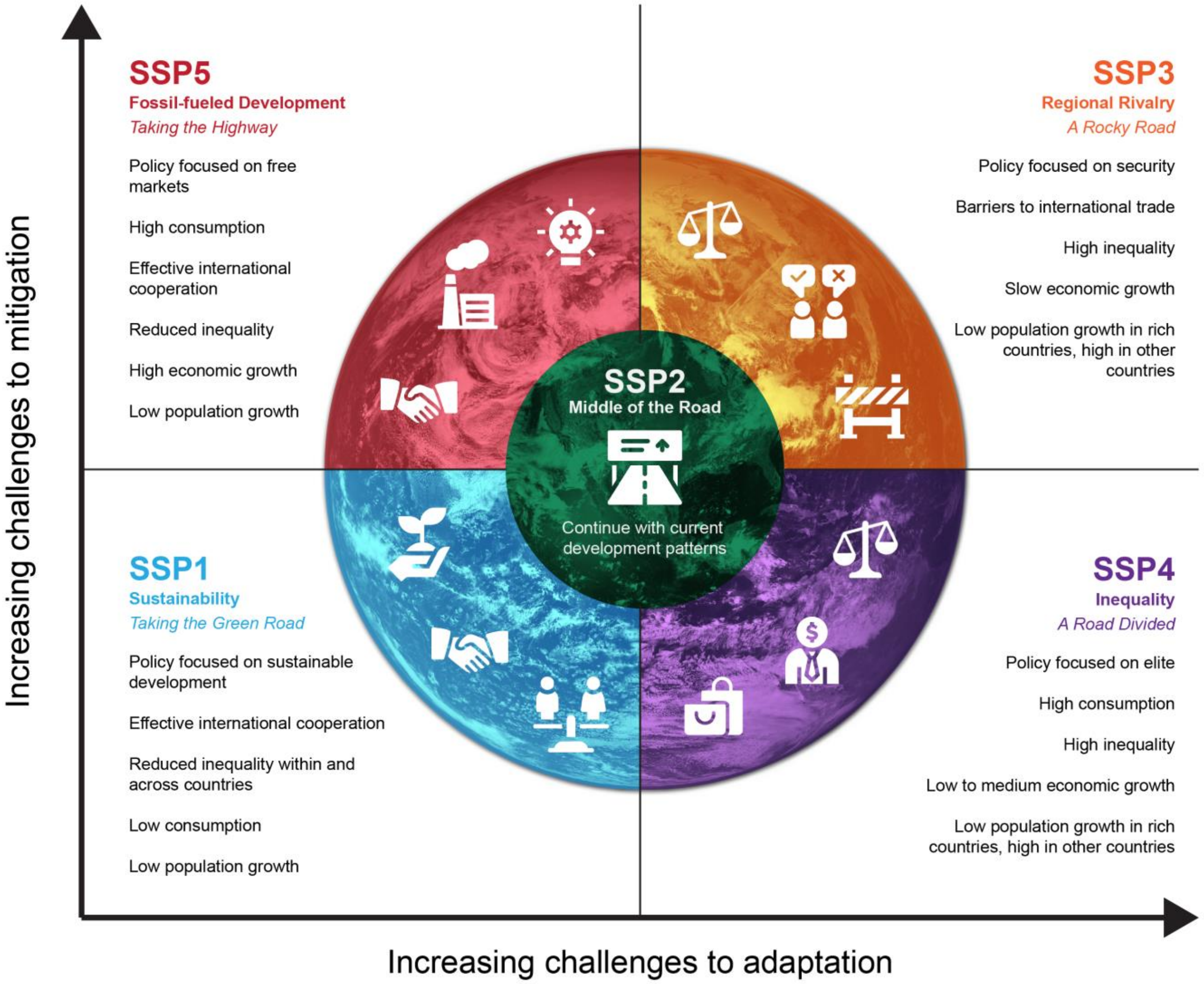
Takeaways

- Climate change poses many challenges to food safety and sustainability of the food system
- Climate scenarios, particularly the SSPs, are one tool to better understand these tradeoffs
- Prioritizing policies consistent with SSP1, particularly effective international cooperation, are key to mitigating both climate-related or exacerbated food safety challenges *sustainably*



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