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Climate Change and U.S. Agricultural Exports

How Future Weather Patterns Will Impact U.S. Competitiveness

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Introduction

Last July 4, as the United States celebrated its 247th Independence Day, Earth endured its hottest day in recorded history. While incidental, with current El Niño patterns driving temperatures up, the record-setting date is nevertheless a snapshot of a larger trend: the month of July was hotter than in most preceding summers, and 2023 is promising to beat yearly temperature records.

That global rising temperatures peaked on Independence Day ironically underscores how future weather trends will change one of the U.S. economy's foundational sectors. Agriculture has been a cornerstone of U.S. exports and one of world trade's dependable staples. In **2021**, agriculture and food-related industries contributed 5.4 percent of U.S. GDP and provided 10.5 percent of U.S. employment. Worldwide, almost **45 percent** of the population lives in households where agricultural activities represent the primary source of employment. Likewise, food systems are essential to sustain economic growth and development; the World Bank reports that agriculture is at least **twice as effective** as other sectors in raising incomes among the poorest segments of the world's population. And agriculture is, of course, essential to feeding this growing population, which is projected to reach **9.7 billion people** by 2050.

The United States has historically maintained a surplus in agricultural trade, but over the past two years, this has slipped into a deficit. The nation ended FY 2022 with a deficit of $3 billion, which the U.S. Department of Agriculture (USDA) predicts will reach $3.5 billion by the end of 2023. This shift has been **driven by** macroeconomic factors such as the persistent strength of the U.S. dollar, poor economic performance in many parts of the world, and tighter monetary policy to combat rising inflation.

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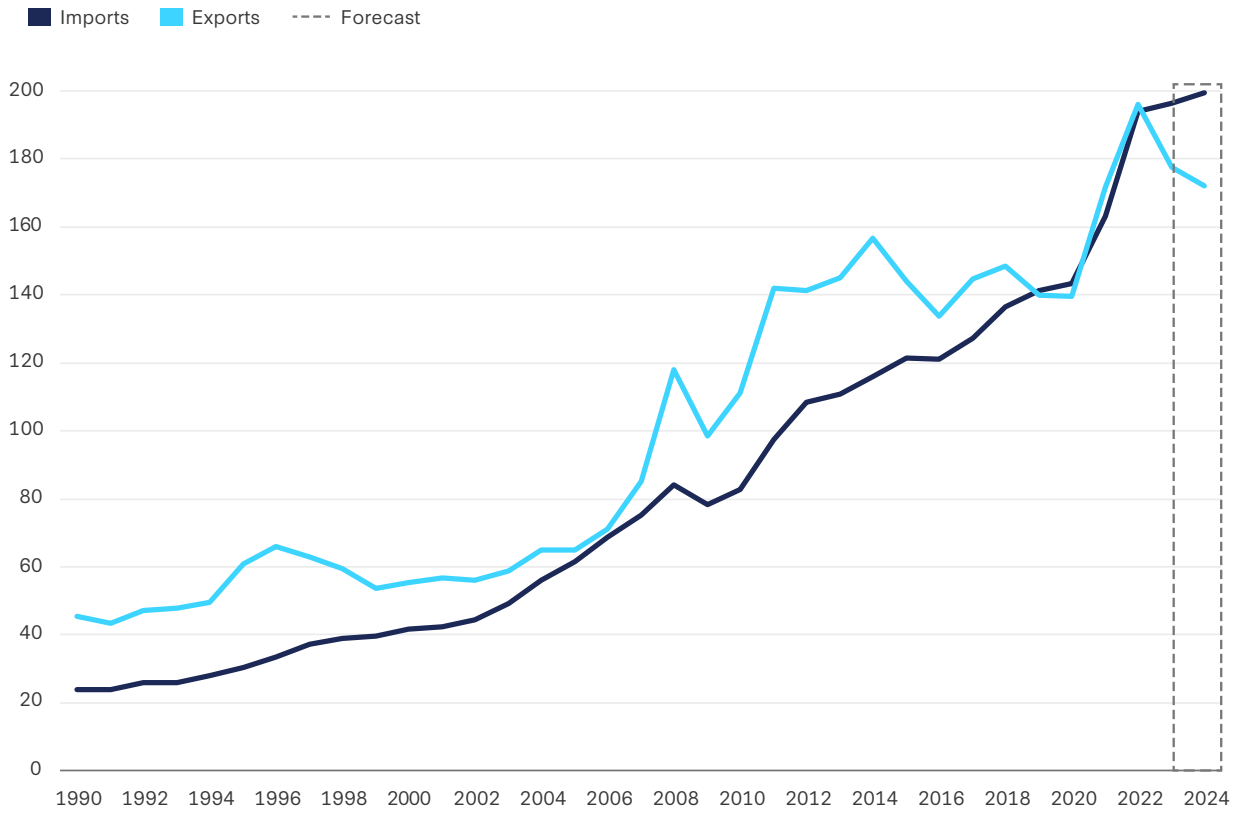
Additionally, the United States is facing production **shortages** in critical export commodities such as corn, wheat, cotton, beef, and poultry. The limited domestic supply of these products is partly driven by the effects that climate change has on production. For example, cotton exports are **expected** to fall by $1.8 billion due to drought in more than half of the U.S. cotton crop regions, leading to declines in production of more than 20 percent.

Figure 1: U.S. Agricultural Trade

USD, Billions



Source: Bart Kenner, Hui Jiang, Dylan Russell, and James Kaufman, *Outlook for U.S. Agricultural Trade: August 2023* (Washington, DC: USDA, August 2023), https://www.ers.usda.gov/topics/international-markets-u-s-trade/u-s-agricultural-trade/outlook-for-u-s-agricultural-trade/.

If agriculture can make global prosperity, it can also break it. Risks associated with poor diets and food insecurity are the **leading** cause of death in the world. Shocks to agricultural production and supply chains can drive prices up and provoke famine and poverty for millions of people across the globe. Between December 2019 and February 2022, the Producer Price Index (PPI) for grains **rose** by 73.5 percent, driven by the impact of the Covid-19 pandemic on corn and wheat prices. Russia's invasion of Ukraine caused a further shock to grain availability, as wheat and corn were heavily supplied by Ukraine, resulting in a **24.1 percent increase** in prices in just the first four months of the conflict. These case studies provide examples of how shocks to agricultural production or trade have the ability to devastate communities en masse.

Climate change is likely to cause more frequent catastrophic events resulting in short-term food instability, as well as long-term changes in weather patterns affecting agriculture output and food

security. The threat is growing, and it is global. It poses existential challenges to our ability to sustainably feed ourselves. In addition, climate change may also, in the medium term, threaten U.S. exports in the sector.

Using wheat, soybeans, corn, cotton, and beef and dairy as case studies, this paper examines how U.S. agricultural output and exports will be affected by climate change in the coming decades. Projections show that while net output is still set to increase for staple crops, yields will become increasingly less efficient than they would have been without climate change's effects. This growing inefficiency will contribute to the United States losing some of its global agricultural exports market share, a trend compounded by other factors such as increased capabilities from other nations. Recent legislation, including the Inflation Reduction Act, takes a reactive approach to this situation rather than a proactive one by attempting to mitigate the negative consequences of climate change on agriculture rather than enabling long-term adaptation and resilience. Early indications are that the farm bill, currently set to be renewed later this year, will take the same approach. This paper concludes with policy recommendations toward making government support of the agricultural sector more effective in tackling climate change's challenges.

Individual Severe Weather Events

The Environmental Protection Agency (EPA) **reports** how, given that rising average temperatures are associated with widespread changes in weather patterns, extreme weather events such as heat waves and large storms are likely to become more frequent and intense. In recent years, a higher percentage of U.S. precipitation has come in the form of intense single-day events. Large floods have become more frequent across the Northeast, Pacific Northwest, and parts of the northern Great Plains. According to **Carbon Brief**, over the past 20 years, 71 percent of the extreme weather events and trends observed by climate scientists were found to be made more likely or more severe by human-caused climate change. This was particularly pronounced—93 percent—for extreme heat events and trends.

Climate change is therefore set to increase the occurrence of severe—and sometimes catastrophic—weather events. Many of these, such as hurricanes and droughts, are bound to have a deleterious effect on the agricultural output of the affected areas. The trends in the five major agricultural goods discussed below give an essential bird's-eye view of the future of U.S. production and exports; however, they fail to capture the increasingly repeated instances of severe events that will disproportionately affect individual farmers and communities. For instance, last spring, farms in the southwest Kansas plains experienced one of their **worst droughts** in recent history. Some parts of southern Kansas and northern Oklahoma even experienced their driest March on record, **according to** the National Oceanic and Atmospheric Administration. The wheat crops planted in the Great Plains are not only integral to feeding cattle but also make the region the epicenter of U.S. bread flour production; consequently, the price of meat, flour, and bread and other baked goods rose sharply around the country after the drought. Another example of severe weather contributing to losses for specific communities' staple products has been the significant decline in Florida's citrus harvest. In 2004, Florida produced 220 million boxes of oranges; as of May 2023, this year's number had fallen to 16 million. The main bane of the Florida citrus industry has been the citrus greening disease, spread by tiny insects known as psyllids, as well as the damage caused by Hurricanes Ian and Nicole—both factors that are exacerbated by climate change.

Trends in Major U.S. Agricultural Exports

Due to favorable climate conditions, an abundance and variety of arable land, and good access to human capital and advanced machinery, the United States has historically been a world leader in agriculture. The United States is the **largest** exporter of agricultural commodities in the world: foreign markets absorb about **one-fifth** of U.S. agricultural production. Developing nations with younger populations, high rise in income, and quick rates of urbanization are driving an increase in demand for U.S. products. On the other hand, demand from wealthier nations—such as Canada, EU countries, and Japan—is experiencing stagnated growth. However, the total value of U.S. products has been declining since 2014, in part due to lower prices of bulk agricultural commodities but also due to the growth in value of U.S. imports in the sector, which have risen faster than U.S. exports, lowering the trade surplus.

Nevertheless, the United States remains an important producer of the world's agricultural goods. It particularly stands out in exporting wheat, soybeans, corn, cotton, and livestock products abroad. These five goods are therefore useful case studies to establish how U.S. agricultural output and exports are projected to fare in the future. Projections show that warmer temperatures are generally a double-edged sword when it comes to crop productivity. In some places, climate change can lead to more growing-degree days when conditions are favorable for crops; however, in all places, climate change will increase killing-degree days during which temperatures are too hot for crops to grow. In other words, while climate change generally spells trouble for agriculture output, different crops in different regions will be affected unequally. As a result, crops affected by climate change can be divided into two categories: those that receive a "climate boost"—if yields are increased compared to what they would be without climate change—and those that bear a "climate burden"—if yields are decreased compared to what they would be without climate change. For instance, a burden on crop yields occurs when extreme heat decreases more crop yields than warmer temperatures or technological advancement can boost them. The **Environmental Defense Fund** highlights this phenomenon well: in Iowa, for example, all of the state's counties will experience climate burdens by 2030 resulting in 5 percent lower yields of corn than they would have been without climate change, and over half of these yields will experience burdens of more than 10 percent. In contrast, wheat yields are **projected** to see an increase of 17 percent in this time period as its growing range is expanded due to higher temperatures.

A GENERAL SHIFT NORTHWARD

The "boosts" and "burdens" of climate change on agricultural output vary according to location and lead to regional shifts in production. Due to the northward shift of warmer temperatures, regions that were once unsuitable for arable agriculture may now become suitable, leading to a movement north and to higher elevations for almost all major crops. Projections vary on the extent to which areas will become more climatically suitable for agriculture; however, the common thread is that agricultural production will continue to **migrate northward** and upward, whereas many southern, central, and eastern regions are projected to become progressively less suitable due to the increase in killing-degree days. Some experts **predict** that climate change will make the U.S. Corn Belt, made up of central and eastern states, unsuitable for cultivating corn by the end of this century. Crop migration will be a crucial element of climate adaptation. However, it is important to note that climate is not the **sole factor** in determining crop location, as political shifts, global demand, and other agriculture practices will all have an effect on how farmers fare in the future and whether or not production will shift to adapt to climate shocks.

As a result, policymakers aiming to mitigate the effects of climate change on agriculture need to target their efforts to specific areas, rather than adopt nationwide policies. In addition, there are significant **benefits** to trade expansion when it comes to reducing climate change impacts, and country-level climate-adaptation plans should consider lowering trade barriers in addition to investing in the resilience of agricultural systems.

CASE STUDIES

Wheat

U.S. wheat exporters ended last year on the **lowest** note in over four decades. In the face of short supplies and cheaper overseas competition, the compound average growth of exports between 2013 and 2022 was **negative 2.05 percent**. The USDA is already projecting even weaker numbers for 2022-2023, with production at a 51-year low of 21.2 million tons.

Table 1: Top Five Wheat Importers and Producers, 2022

Importers in 2022 (USD)	Producers (tons)
Indonsia – 3.8 billion	China – 138.0 million
Egypt – 3.8 billion	European Union – 135.0 million
China – 3.7 billion	India – 103.0 million
Turkey – 3.4 billion	Russia – 92.0 million
Italy – 2.8 billion	United States – 45.0 million

Source: International Trade Centre, "Trade Map" (Importers for Wheat and Meslin), accessed October 17, 2023, https://www.trademap.org/; and M. Shahbandeh, "Global Leading Wheat Producers 2022/2023," Statista, March 10, 2023, https://www.statista.com/statistics/237912/global-top-wheat-producing-countries/.

The United States is the world's fourth-largest individual wheat producer in the world, when the combined production of EU countries is excluded. China, India, and Russia top it, accounting altogether for about 41 percent of the world's total wheat production. Trends in global output related to the effects of climactic factors depict a varied picture depending on geography. A **study** examining data from China's top three wheat-producing provinces from 1992 to 2020 shows how climactic factors such as temperature and rainfall negatively influenced wheat production in Henan Province, whereas they positively contributed to production in Hebei Province; meanwhile, temperature negatively influenced wheat production in Shandong Province, but rainfall contributed positively to it.

When it comes to the historical effects of climate change on U.S. wheat production, the results depend on the different varieties of plants. Between 1960 and 2018, studies show that winter wheat breeding lines' yields declined by 3.6 percent per 1 degree Celsius warming, whereas the check variety—the point of comparison for the study—declined by 5.5 percent per 1 degree. Despite warmer temperatures, future U.S. yields for wheat are projected to rise in some regions due to anticipated increases in precipitation and carbon fertilization. In addition, climate change will bring about multiple weather changes that will have different and sometimes contradictory effects on output. Consider the case of Kansas: **projections** show that the state's total freeze days will be lower by 17 percent by 2030 and 23 percent by 2050, and spring precipitation will tend to increase by 5 percent. Yet, by 2030, 8 percent of Kansas counties will experience

a drop in winter wheat yields of over 5 percent from what they would be in the absence of climate change. That is because, despite the benefits to wheat yields brought about by Kansas' lowered freeze days and increased precipitations, models also predict that total spring killing-degree days will rise statewide by 58 percent by 2030 and 96 percent by 2050. In other words, the state's wheat exposure to extreme heat will likely have a larger negative impact on wheat yield than benefits brought about by climate change.

U.S. exports are currently projected to stabilize at around 26 million tons over the next decade. Because other nations will fare better in the global wheat production market, the United States' **share** of world exports will decrease from 13.4 percent in 2021–2022 to 12.1 percent by the end of 2030. Only the European Union and Ukraine are currently **set to exhibit** a rising world export share by 2030–2031, as the European Union's share will increase from 16.1 percent to 18.7 percent and Ukraine's from 8.2 percent to 9.6 percent throughout the 2020s. However, with 2030 come more severe changes to wheat production, under a high greenhouse gas (GHG) emissions scenario outlined by **NASA**. According to that **model**, wheat yields in African and South Asian countries will decline by 15 percent and 16 percent respectively by the middle of the twenty-first century. These losses may be offset by additional—yet increasingly less effective—financial investments and human efforts in other less affected regions, such as Canada and the North China Plains. However, even those gains are set to level off by the middle of the century.

Soybeans

Unlike wheat, U.S. soybean exports have been growing steadily at a compound annual average of 4.8 percent. Soybeans are a key aspect of meat production, as soybean meals **provide** reliable protein and nutrients to poultry, hogs, and beef and dairy cattle. Last year, the United States was the **second-largest** exporter of soybeans in the world, second only to Brazil. In addition, the 2022 export value of soybeans reached $34.39 billion. Soybeans are a critical part of U.S.-China agriculture trade, as the value of the Chinese export market is $17.87 billion. Before 2018, U.S. soybean exports to China represented **more than 60 percent** of all U.S. soybean exports. However, in the context of rising trade tensions following the Trump administration's start in office, U.S. exports of soybeans to China **fell** by 45 percent, from $12.3 billion in 2017 to $3.1 billion in 2018. As a result, China has turned to Brazilian exports as well as taking action to boost domestic production and reduce its **soybean dependence**. The United States now relies on demand for soybeans in the biodiesel and renewable fuels market, which is fast-growing but unlikely to offset lower demand by China.

Table 2: Top Five Soybean Importers and Producers, 2022

Importers (USD)	Producers (tons)
China – 61.0 billion	Brazil – 152.0 million
Mexico – 2.6 billion	United States – 118.0 million
Japan – 2.6 billion	Argentina – 49.0 million
Germany – 2.2 billion	China – 18.0 million
Egypt – 2.1 billion	India – 12.0 million

Source: "Soya beans (soybeans), Imports and Exports, 2022," TrendEconomy, May 14, 2023, https://trendeconomy.com/data/commodity_h2/1201; and "Soybeans," USDA Foreign Agricultural Service, September 26, 2023, https://www.fas.usda.gov/data/commodities/soybeans.

Soybeans are particularly vulnerable to the effects of climate change. U.S. soybean yields are **projected** to decline by up to 24 percent from their normal upward trends by the end of the twenty-first century. Negative effects will also be felt in the short run. For instance, half of the counties in **Minnesota** (the United States' third-largest soybean-producing state) will see yields drop by over 5 percent from what they would have been without climate change, and 17 percent will experience declines of over 10 percent. The state will receive a variety of boosts and burdens: models predict that total growing-degree days will increase statewide by 12 percent by 2030 and 20 percent by 2050, but instances of killing-degree days will rise more significantly, by 55 percent by 2030 and 105 percent by 2050.

Exports are nevertheless expected to rise, both globally and from the United States, as countries' agricultural investments continue to boost yields. For instance, worldwide production will **increase** by 21.4 percent in the next decade. Looking at these trends alone, of course, does not reveal the full picture, as production would have been more efficient without the effects of climate change. In addition, the United States is set to suffer more from these consequences than its competitors in this sector—Brazil and Argentina—as its **share** of global exports will decline from 34 percent today to 29.5 percent by 2030.

Corn

The United States is the world leader in corn production. It outpaced the second-largest corn producer, China, by over 70 million tons last year. U.S. exports have also experienced a significant rise in the past decade, growing by an average of 11.3 percent between 2013 and 2022 to reach a value of $18.61 billion. Nevertheless, much like soybeans, the current abundance of corn crops is being threatened by the ongoing and impending effects of climate change.

Table 3: Top Five Corn Importers and Producers, 2022

Importers (USD)	Producers (tons)
China – 7.1 billion	United States – 353.0 million
Japan – 5.8 billion	China – 274.0 million
Mexico – 5.4 billion	Brazil – 126.0 million
Republic of Korea – 4.2 billion	Argentina – 55.0 million
Spain – 3.7 million	European Union – 54.0 million

Source: M. Shahbandeh, "Import value of corn worldwide in 2022, by leading country," Statista, August 15, 2023, https://www.statista.com/statistics/1167839/leading-global-corn-importers/; and "Corn," USDA Foreign Agricultural Service, October 2, 2023, https://www.fas.usda.gov/data/commodities/corn.

Estimates regarding the effects of climate change on corn production vary, though they all present a bleak picture. The Intergovernmental Panel on Climate Change's (IPCC) most recent **report** estimates that the world's corn crop yields will decline by 24 percent by the end of the century under a high GHG emissions scenario. Moreover, Stanford research **states** that "at the current rate of sensitivity, climate change models indicate that corn yields could decline as much as 15 percent over the next 50 years; however, if sensitivity of these plants continues to increase as well, losses could amount to as much as 30 percent." The most significant reductions for foreign coarse grain are **forecast** in corn production

for Argentina and Brazil, due to drought conditions in the region exacerbated by climate change. This reduction is partly offset by increased levels of production in China.

U.S. production will suffer as well. At the start of 2022, corn production was **down** 9 percent from 2021. Nearly all counties in **Iowa**, the United States' largest corn-producing state, will see corn yields that are more than 5 percent lower than they would have been without climate change by 2030. More than half will see declines of 10 percent or greater. While the state's growing-degree days will increase statewide by 11 percent by 2030 and 18 percent by 2050, killing-degree days will increase by 57 percent by 2030 and by 94 percent by 2050. While the country's **exports** are expected to increase in absolute terms by 11.4 million tons in the next decade, its share of world exports will decrease from the current 33 percent to about 30.5 percent as a result of these heightened challenges for U.S. corn production. The United States will mainly lose out to Brazil—the only major exporter with a **projected** increase in market share, from 21.9 percent in 2021–2022 to 26.1 percent in 2030–2031.

Cotton

The United States is the world's leading cotton exporter. In 2022, exports of cotton were valued at $9.02 billion, growing a compound average of 4.9 percent between 2013 and 2022. However, while the United States is **expected** to remain the leading cotton exporter with exports projected to rise by approximately 0.9 percent annually, its market share is predicted to **decline** from 35.7 percent in 2021 to 32 percent in 2030–2031. As with the soybean industry, China is the lead importer of raw cotton and the effects of the trade tensions between the two nations is felt by the United States in the loss of shares in Chinese raw cotton imports.

Table 4: Top Five Cotton Importers and Producers, 2022

Importers (USD)	Producers (tons)
China – 9.3 billion	China – 5.8 million
Bangladesh – 8.6 billion	India – 5.3 million
Vietnam – 5.6 billion	United States – 3.8 million
Turkey – 4.8 billion	Brazil – 2.5 million
Indonesia – 2.2 billion	Pakistan – 1.3 million

Source: International Trade Centre, "Trade Map" (Importers for Cotton), accessed October 17, 2023, https://www.trademap.org/; and M. Shahbandeh, "Global Leading Cotton Producers 2022/2023," Statista, September 19, 2023, https://www.statista.com/statistics/263055/cotton-production-worldwide-by-top-countries/.

After China and India, the United States is the third-largest global cotton producer. While cotton production is **projected** to grow by 2 percent annually, this crop is grown in a warm and humid climate and the effects of climate change will undermine yields in some areas. By 2040, 40 percent of cotton-producing regions will see shorter growing seasons due to rising heat, and droughts could affect 50 percent of global crops, according to a report produced by Cotton 2040, an initiative working for a more sustainable and climate-resilient cotton industry. The effects of climate change on cotton are expected to be most severe in **two regions** of the world: the cotton fields located along the Nile river in

northern Sudan and cotton-growing regions in western and southern Asia, southeast Iraq, central Iran, southern Afghanistan, and Pakistan.

In the United States, a **2020 study** found that Arizona is already experiencing lower production of upland cotton due to heat and drought worsened by climate change. It is predicted that future yields of cotton could drop by up to 40 percent between 2036 and 2065 in this region. In 2022, cotton farmers in Texas suffered **record losses**, having to abandon 74 percent of planted crops due to extreme drought made worse by climate change. Additionally, the Ogallala aquifer, stretching from Wyoming to Texas, provides water to the southwestern cotton crop but is declining at a rapid pace accelerated by climate change causing **projected** droughts over much of the region in the next 50 years. Groundwater is a critical renewable resource and its importance for agriculture cannot be overstated.

The Importance of Groundwater for Irrigation

Groundwater and aquifers play a key role in the irrigation of crops and serve as **"nature's insurance"** for the agricultural sector. By ensuring that there is fresh water available to sustain crops, they provide a **buffer** that is critical for regions facing climate shocks such as drought and unreliable precipitation. Groundwater extraction for irrigation has been a necessity for many parts of the United States to meet food demands. More than 70 percent of groundwater in the United States is used for agricultural irrigation, making the sector the **largest** user of groundwater in the country, and the Ogallala aquifer accounts for one-third of all irrigated agriculture in the United States. However, some sources of groundwater can take several years to **replenish**. Therefore, the excessive extraction of nonrenewable groundwater and long periods without precipitation to feed these resources can have devastating impacts on the environment—including land subsidence, water quality degradation, and rising sea levels.

As sources of groundwater are depleted faster than they can be replenished, the world becomes increasingly vulnerable to the effects of climate change; the consequences of mismanaging groundwater will be progressively more harmful as climate shocks become more frequent and severe. Sustainable water use is therefore fundamental to maintaining crop production in the context of climate change. The United States' dependence on groundwater for irrigation has resulted in unsustainable uses of aquifers, and wheat, cotton, and corn are among the **top five** crops leading to the most depletion of groundwater resources globally. For example, roughly 18 percent of the domestic grain supply in the United States is **produced** in locations that require unsustainable use of aquifers.

Livestock

Products sourced from livestock also play a large role for the U.S. agricultural sector. The United States is the largest global producer of beef, and its exports of beef and beef products are **valued** at $11.68 billion, with a compound annual growth rate of 6.6 percent between 2013 and 2022. The United States is also the second-largest producer of dairy after the European Union; U.S. exports of dairy were valued at $9.51 billion in 2022, growing a compound average of 3.6 percent between 2013 and 2022.

Table 5: Top Five Beef Importers and Producers, 2022

Importers (USD)	Producers (pounds)
China – 22.0 billion	United States – 28.4 billion
United States – 5.2 billion	Brazil – 22.8 billion
South Korea – 5.0 billion	China – 15.7 billion
Japan– 3.9 billion	European Union – 15.0 billion
Egypt – 2.9 billion	India – 9.6 billion

Source: "Livestock and Poultry: World Markets and Trade," USDA Foreign Agricultural Service, July 12, 2023, https://apps.fas.usda.gov/psdonline/circulars/livestock_poultry.pdf.

Table 6: Top Five Milk Importers and Producers, 2022

Importers (USD)	Producers (tons)
China – 4.4 billion	European Union – 143.9 million
Algeria – 1.7 billion	United States – 103.0 million
Mexico – 1.4 billion	India – 97.0 million
Indonesia – 1.2 billion	China – 39.2 million
Netherlands – 1.0 billion	Russia – 32.1 million

Source: International Trade Centre, "Trade Map" (Importers for Milk and Cream, Concentrated or Containing Added Sugar or Other Sweetening Matter), accessed October 17, 2023, https://www.trademap.org; and M. Shahbandeh, "Major producers of cow milk worldwide in 2022, by country," Statista, August 30, 2023, https://www.statista.com/statistics/268191/cow-milk-production-worldwide-top-producers/.

Changes in climate will affect livestock and animal products both directly and indirectly. For example, the impact of climate change on grain crops such as wheat and corn will also threaten the feed supplies for grain-fed animals. Additionally, rising temperatures caused by climate change will have **direct impacts** on the animals, as deviations of even 2 to 3 degrees Celsius cause heat stress and increase vulnerability to disease, reduce fertility, and reduce milk production—while a deviation of between 5 and 7 degrees often results in death of the animal. A **study** conducted in 2014 estimated losses of 1.9 percent in U.S. dairy production due to climate change impacts and predicted that these losses could increase to 6.3 percent—an equivalent of $2.2 billion a year—by the end of the twenty-first century. Another **study** predicts that the dairy and meat industries will lose $39.94 billion per year to heat stress by the end of the century.

The effects of climate change on livestock and animal products are not just felt by the United States but also by other global producers. For example, changes in climate led to the steady decline of the **Australian dairy industry**, which was once a major producer—with 16 percent of global dairy trade in the 1990s—but continues to shrink, measuring only 6 percent of global dairy trade in 2018. The number of Australian dairy farms also declined by nearly three quarters between 1980 and 2020. According to the USDA, this decline is due to dry conditions in key milk-producing regions, along with

worker shortages. In India, another major dairy hub, producers are **considering** purchasing cooling equipment to combat the strain that more prevalent heat waves have placed on dairy cows, while in **France**, climate change is affecting the ability to produce premium cheese.

While climate change will have a significant effect on animal agriculture, it is also important to note that raising livestock for human consumption is one of the main contributors to climate change, as methane produced by cattle is 28 times more **potent** in warming the atmosphere than carbon dioxide. Additionally, livestock agriculture is a **major contributor** to deforestation, biodiversity loss, and water pollution.

AGRICULTURE'S EFFECT ON CLIMATE CHANGE

The population boom of the past century has caused demand for food products to skyrocket. As a result, the agricultural sector now **generates** 19 to 29 percent of the world's total GHG emissions. The current status quo presents a vicious cycle in which agricultural practices contribute significantly to the climate change problem, which in turn render our agricultural practices less and less efficient—meaning that, all else equal, an increasing amount of carbon and methane emissions will be needed to produce the same output. It also means that, as more arable land becomes impractical for farming, farmers will have to **shrink** the globe's remaining forest to have access to viable growing areas, thus reducing those regions' ability to absorb carbon. This issue is compounded by the fact that the world population is **expected** to grow by 3.1 billion people between 2020 and 2100 before leveling off.

A way to reduce agriculture's GHG emissions is to incentivize climate-smart agriculture (CSA), an approach that promotes green and climate resilient practices. It involves sustainable increases of agricultural productivity and incomes, adapting and building resilience to climate change, and reducing or removing GHG emissions from agriculture where possible. However, in practice, CSA is **context-specific** and depends on socioeconomic, environmental, and climate factors. The UN Food and Agriculture Organization recommends **five actions** to implement a CSA approach: (1) expand the evidence base of current and projected effects of climate change, (2) support enabling policy frameworks, (3) strengthen national and local institutions that empower and motivate farmers, (4) enhance financing options that link climate and agricultural finance and investments from the public and private sector, and (5) implement practices at a local level through local projects and institutions to identify and implement suitable climate smart options.

Another important facet of agriculture's unsustainable practices lies in waste. About a **third** of the world's food produced is currently lost or wasted. In the United States, **Feeding America** reports that about 40 percent of food goes to waste—about 120 billion pounds of food each year. While the USDA **estimates** that about 30 percent of food in the United States goes uneaten at the retail and consumer level, food loss occurs throughout the supply chain—including at the farm level. Farm-based food waste occurs for several reasons. Sometimes, market prices for crops may be too low to justify the costs involved with making additional passes to harvest additional crops. Labor may also be hard to come by, and crops are left in the field to rot. Lastly, growers can encounter difficulties finding buyers for their product toward the end of the harvest period, as wholesale buyers switch to other suppliers when better-quality products become readily available in different regions. All this waste currently leads to a gap between production capabilities and actual agricultural goods consumption larger than the impending production inefficiencies that will occur because of climate change.

A variety of tools are available to policymakers to reduce food waste. For example, by introducing food redistribution programs, surplus food can go to those in need instead of being wasted. Tax incentives to harvest, prepare, and store food for donation can help facilitate the redistribution process. Another example of incentives to prevent food waste is the **Farm Storage Facility Loan Program** (FSFL), which provides low-interest financing to help producers build or upgrade storage facilities.

Preventing pests is essential in minimizing food loss, as they are a large contributor to food waste. **Crop protection** involves the use of different types of control measures (such as chemical, biological, physical, and cultural controls) to prevent and monitor for pests as well as intervene when needed to prevent losses.

Food waste monitoring and reporting is also important to track where food waste is taking place in the supply chain and to enable data-driven policies and accountability. In the United States, the USDA and EPA **committed** to the U.S. 2030 Food Loss and Waste Reduction Goal in 2015, which seeks to cut food loss and waste in half by 2030. However, these agencies do not have a baseline for food loss, which makes measuring progress difficult. There is also an **energy** potential to leftover crops that is underused. Although it would require an upfront injection of capital, leftover crops can be diverted from waste into biofuel to power back into the farm or local utility. Renewable diesel, made from vegetable oils like soybeans or animal fats from meat processing plants, is chemically **equivalent** to petroleum-based diesel and can be used as a substitute in existing engines without being modified. It is therefore a pillar of the U.S. decarbonization strategy, and it could mitigate waste by turning over-capacity into fuel with a carbon intensity around 65 percent lower than its traditional counterparts. Finally, education is vital to reducing food waste. Through public awareness campaigns or labeling, producers and consumers can be educated about the impact of food waste and what they can do to prevent it. For example, a clear labeling campaign could help consumers understand when their food is "expired" but still safe for consumption.

U.S. Agriculture and Climate Change Legislation

The U.S. agricultural sector has long been supported by landmark pieces of legislation, recognizing and cementing the sector's important place in the nation's economy: the original farm bills were enacted during the 1930s as part of President Franklin D. Roosevelt's New Deal legislation. The Inflation Reduction Act (IRA) and the upcoming farm bill renewal continue to build upon the legacy of congressional support for farmers. Both pieces of legislation aim to provide some climate change–related funding for the agriculture sector. However, so far, much of the previous farm bills' support has aimed to compensate the agriculture industry for climate-related trends and events rather than proactively tackling the issue. On the other hand, half of the IRA's agriculture funding lies in conservation programs, which aim to assist individual farmers engaging in more sustainable practices. In other words, the IRA and the anticipated farm bill seem to be taking an ex post approach rather than focusing on proactive measures to enable the industry to adapt to the new long-term climate reality. With renewals set for this year, U.S. policymakers have the opportunity to implement policies to facilitate practices that are more adaptable to changing weather patterns—and therefore more sustainable.

The Inflation Reduction Act

The IRA provides a significant amount of funding to mitigate climate change's effects on agricultural output. Nearly half of the $40 billion in funding for agriculture, forestry, and rural development will go to agricultural conservation programs—an unprecedented investment into climate-smart agriculture. These programs are **focused** on improving environmental performance in agriculture and the adoption of climate-smart practices. For example, the Environmental Quality Incentives Program (EQIP) and Conservation Reserve Program (CSP) provide financial assistance to farmers who adopt, install, or maintain conservation practices on land in production. The Agricultural Conservation Easement Program helps preserve agricultural land that might otherwise be developed, and the Regional Conservation Partnership Program funds a wide range of practices related to solving conservation problems on a regional or watershed scale. Conservation programs are incredibly **competitive,** with 73 percent of applicants to CSP and EQIP turned away in 2022.

The **conservation programs** aim to assist up to 280,000 farmers and ranchers to protect around 125 million acres of land. The IRA's conservation efforts allow farming communities to implement changes to improve grazing conditions through better soil health and air quality and to develop wildlife habitats, among others. In short, the opportunities help landowners and managers enact more sustainable practices. The act also offers debt relief for overburdened borrowers of loans administered by the Farm Service Agency and financial assistance for underserved farmers and ranchers. These programs are critical to promoting not just climate mitigation but also climate adaptation. However, the future of this funding is **uncertain**, and it will be shaped by the outcome of the 2023 farm bill reauthorization as well as legislative attempts to divert some of this funding away from climate and conservation programs.

Table 7: Breakdown of the IRA's Agriculture, Forestry, and Development Budget

IRA agricultural conservation program funding	**Total: $19.5 billion**
Environmental Quality Incentives Program	$8.45 billion
Regional Conservation Partnership Program	$4.95 billion
Conservation Stewardship Program	$3.25 billion
Agricultural Conservation Easement Program	$1.4 billion
Conservation technical assistance	$1 billion
Debt relief funding	**Total: $3.1 billion**
USDA technical assistance and customer service support for underserved farmers, ranchers, and foresters	$125 million

Grants and loans for eligible entities to improve land access for underserved farmers, ranchers, and forest landowners, including ▪ veterans ▪ limited resource producers ▪ beginning farmers and ranchers ▪ farmers, ranchers, and forest landowners living in high poverty areas	$250 million
USDA Equity Commission	$10 million
Financial assistance to farmers, ranchers, or forest landowners determined to have experienced discrimination in a USDA lending program before January 1, 2021	$2.2 billion
Administrative costs associated with carrying out this section of the IRA	$24 million
Funding to mitigate the impacts of drought in the Western Reclamation states	**Total: $4 billion**
New biofuels infrastructure	**Total: $500 million**

Note: Each budget breakdown by category represents a summary of the programs and does not include every item.
Source: "Inflation Reduction Act Investments in USDA Loan and Conservation Programs," USDA Farmers.gov, https://www.farmers.gov/loans/inflation-reduction-investments.

THE FARM BILL

The farm bill, a substantial package of legislation passed every five years, has a significant impact on farming livelihoods and the kinds of food products grown nationwide. The existing farm bill, the Agriculture Improvement Act of 2018, was enacted into law in December 2018 and expires this year. It is therefore set to be renewed. This year's farm bill is already expected to be the first trillion-dollar version, with a **baseline** set at $1.51 trillion.

This provides a **estimation** of future federal mandatory spending if the current law continues, and it serves as a benchmark for any changes made in the 2023 legislative session. Past farm bills have both fallen below and exceeded their baselines. For **example**, the 2002 farm bill exceeded its baseline by $73 billion over 10 years, the 2014 farm bill reduced spending by $16 billion over 10 years, and the most recent 2018 farm bill was budget-neutral as it offset reductions in some titles with increases in others. In addition, the farm bill is notoriously a battleground for partisan politics fueled by competing interests between urban and rural populations and contentious issues such as agricultural subsidies, nutrition assistance, and conservation. It is therefore a highly complex process, and the outcome of the next bill is difficult to predict with certainty—but the baseline provides a foundation and is what the package will be scored against.

Based on this baseline, a large majority of the farm bill's projected budget—a whopping $1.2 trillion—is currently estimated to go to the Supplemental Nutrition Assistance Program (SNAP). SNAP has been hailed as the nation's best tool in reducing hunger and food insecurity. As of December 2022, SNAP

was **helping** over 42 million low-income individuals in the United States afford a nutritional diet through debit card benefits usable to purchase food at specific retailers. On average, SNAP recipients **receive** about $6 per person per day in food benefits. The program goes beyond tackling food insecurity, however, and can be used as a tool to address multiple social challenges. For instance, SNAP's Employment and Training program (SNAP E&T), likely to be included in the bill, helps SNAP participants fulfill any work requirements to which SNAP may subject them by providing case management alongside job search services, education, training, and work experience. According to the **Center for Law and Social Policy**, SNAP contributes to lifting millions of people out of poverty and boosting local economies by protecting short- and long-term health, education, and employment outcomes for children and families. One **study** also showed that participating in SNAP is associated with less GHG emissions from food spending. While approximately 24 percent of households in the bottom fifth for emissions participated in SNAP, only 9 percent of households in the top fifth for emissions participated in the nutrition program.

Table 8: 2023 Farm Bill Funding Estimates Based on the 2018 Baseline

2023 Farm Bill Scoring Baseline for Agricultural Programs and SNAP	Total: $1.51 trillion
SNAP (Nutrition)	$1,223.1 billion
Crop Insurance	$101.3 billion
Commodity and Related Programs ▪ Price loss coverage ▪ Agricultural risk coverage ▪ Disaster programs ▪ Other Title I ▪ Dairy	$68.6 billion
Conservation ▪ Conservation Reserve Program ▪ Environmental Quality Incentives Program ▪ Conservation Stewardship Program ▪ Agricultural Conservation Easement Program ▪ Regional Conservation Program ▪ Other	$60 billion
Inflation Reduction Act	$34.7 billion
Administrative Commodity Credit Corporation spending	$10 billion
Trade ▪ Food for Progress ▪ Agricultural Trade Promotion Program	$5 billion

Horticulture ▪ Specialty Crop Block Grant Program ▪ Plant pest and disease ▪ Local agriculture market	$2.1 billion
Research ▪ Organic agriculture research ▪ Specialty crop research	$1.3 billion
Miscellaneous ▪ Animal disease management ▪ Farming opportunities	$800 million
Energy ▪ Rural Energy for America	$500 million

Source: "Minority Analysis: The May 2023 Farm Bill Scoring Baseline," United States Senate Committee on Agriculture, Nutrition, and Forestry, May 15, 2023, https://www.agriculture.senate.gov/newsroom/majority-blog/minority-analysis-the-may-2023-farm-bill-scoring-baseline.

Another key aspect of the farm bill—and the number one priority of most of the farming industry amid farm bill debates—is crop **insurance**. This is a safety net that triggers payment on a majority of historical base acres if either country revenue or marketing year average price for a given crop falls below an established benchmark. This kind of guarantee can offer essential compensation if climate change-related events occur; however, many U.S. crops have yet to be properly insured, especially in the face of rising climate change-related weather events. According to Elizabeth Hinkel, the president of the Pennsylvania Corn Growers, around **45 percent** of corn acres in her state are not insured, so farmers are liable for costs if their crops fail due to climate or other disasters. As the farm bill approaches its renewal, crop insurance will be among the top concerns in the debate. For farmers experiencing the devastating effects of extreme climate events, maintaining or even increasing crop insurance programs is a high priority. However, some analysts, such as the U.S. Government Accountability Office, **suggest** that reducing crop insurance costs—particularly when it comes to high-income participants and insurance companies—could help fund other priorities. Others call for **changes** to these programs so that they benefit small to mid-sized farms and not just large corporate commodity farmers. At present, many of these smaller farmers have not yet been able to enroll in the federal crop insurance program for several reasons, including limited policy availability, bureaucratic red tape (including burdensome paperwork), and insufficient outreach and education. **Analysis** from the American Enterprise Institute reported that "farms in the top 10 percent of the crop sales distribution received approximately 68 percent of all crop insurance premium subsidies." Other **issues** include the massive scope of the program, lack of transparency, and crowding out of private risk management solutions. There are also **arguments** to be made that crop insurance discourages farmers from adapting to mitigate climate change or shifting their production to less fragile lands, thereby increasing soil erosion and exacerbating negative climate impacts.

Policy Recommendations

Aside from insurance, climate-related components are scarce in the farm bill's current projections. Conservation is set to play a relatively small role in the farm bill: about 4 percent of funding is expected to be devoted to conservation efforts. In addition, the current debate around the farm bill seems to be focused on redirecting climate-related funding rather than enhancing it. Senator John Thune said he wanted to provide more flexibility in how the IRA's conservation funding can be used through the farm bill. Capitol Hill's most conservative wing is also **discussing** repealing some of the IRA's green energy funding altogether. The upcoming farm bill renewal provides opportunities for policymakers to tackle the issue more effectively and prepare the nation's sector to become more adaptable and resilient, such as through the following policy recommendations:

1. **Launch a farm bill program to assess what regions of the United States are going to see their agriculture production capabilities expand or shrink due to changes in climate.**
    - Even under moderate-emissions scenarios, the cultivation geographies of corn, soy, cotton, and wheat will all shift north, with the Corn Belt of the upper Midwest becoming unsuitable to the cultivation of corn by 2100. More severe emissions scenarios exacerbate these changes. The United States has the means and territory to shift production of major crops in the short term, and it should consider how to efficiently phase into that transition throughout the twenty-first century.
2. **Identify ways of incentivizing sustainable agriculture practices that are more climate-friendly and climate-resilient.**
    - Expand investment in climate-smart agriculture (**CSA**). Given its aim to produce more and better food to improve nutrition security and boost incomes, reduce vulnerability to climate-related shocks and improve capacity to adapt to longer-term stresses, and pursue lower emissions, CSA will help yields regain some efficiency and lower the industry's contributions to GHG emissions.
    - Incentivize ways of mitigating food waste. Farm-level food waste can be mitigated through several avenues. For example, investments in research and development to drive innovation in pest-management solutions would reduce pest-related waste. Surplus channels that sell below-grade crops would help redistribute products that do not get sold on the market. In addition, surplus in some crops could be used to produce biodiesel as a less carbon-intensive fuel alternative.
3. **Leverage SNAP assistance to incentivize alternatives to carbon-intensive goods.**
    - SNAP is one of the country's best tools to combat food insecurity. It helps feed some 47 million individuals each year by supporting their access to groceries. However, the program could be adjusted to gear incentives toward less carbon-intensive food products that contribute to climate change, such as beef. Alternatives to these carbon-intensive goods should be available for a discount to SNAP-assisted shoppers as a way to encourage their consumption and reduce their purchases of more carbon-intensive counterparts. While participation in SNAP is already **associated** with fewer GHG emissions from food spending, there is room for incentives and further progress.

4. **Enhance crop insurance coverage.**

    - With the rise of killing-degree days and severe weather events such as hurricanes and droughts, the share of crops that fail will increase. As a result, more farmers will require expanded insurance coverage for their crops to remain financially viable over time. In addition, crop insurance coverage should be more accessible to smaller farmers, rather than concentrated in large part on the top producers. Expanded coverage would promote farmers' financial stability, facilitating their investments in longer-term adaptation methods. However, insurance without guardrails may provide incentives to continue farming on fragile lands, so crop insurance coverage should come with clauses stipulating that beneficiaries will aim to phase out unsustainable practices that lead to soil erosion and higher carbon footprints.

Conclusion

Climate change has already affected the U.S. agricultural landscape. It has caused more frequent instances of individual severe weather events—such as extreme heat waves and floods—which are bound to have a negative effect on the affected areas' agricultural output; a growing number of individual communities struck by disaster are already beginning to feel the outsize effect of climate change. Climate change will also impact agricultural output in the United States on a macro scale. While net U.S. yields in wheat, soybeans, corn, and cotton are set to increase, they are projected to become less efficient over time as extreme weather events and killing-degree days grow more commonplace. This lower efficiency will contribute to the United States losing some of its share of global exports to other nations. Likewise, the dairy and meat industries are estimated to lose around $40 billion per year to heat stress alone, and dairy production will likewise decline between 2 and 6 percent. All of these developments hurt the country's importance as a global agricultural supplier—a major source of soft power for the United States.

Previous iterations of the farm bill have been, in large part, focused on mitigating the financial losses incurred by harmful weather patterns' consequences on farmers as well as on nutrition programs. Both of these efforts constitute important pieces of the puzzle, but they do not fully enable the agriculture sector to adapt to new climate conditions or attempt to mitigate agriculture's harmful effects on climate change in the long run. Congress' upcoming consideration of the farm bill presents U.S. policymakers with the opportunity to further embed climate change adaptation and mitigation into the country's agricultural sector.

The strength of the United States in the agricultural export market has already been waning. While the country is not projected to lose a large amount of global market share related to other nations, it will nevertheless decrease in importance as its crop yields become less efficient and its livestock suffer more killing-degree days and individual severe weather events. In addition, maintaining or increasing output will become more expensive as weather patterns grow more unstable. To retain some of its primacy on the world's agriculture stage, the United States will need to take more proactive steps to encourage the agriculture sector's sustainability in the face of climate change. ■

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