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ALSO IN THIS ISSUE

Russian Weaponization of Food Rattles Global Markets

Colin A. Carter and Sandro Steinbach

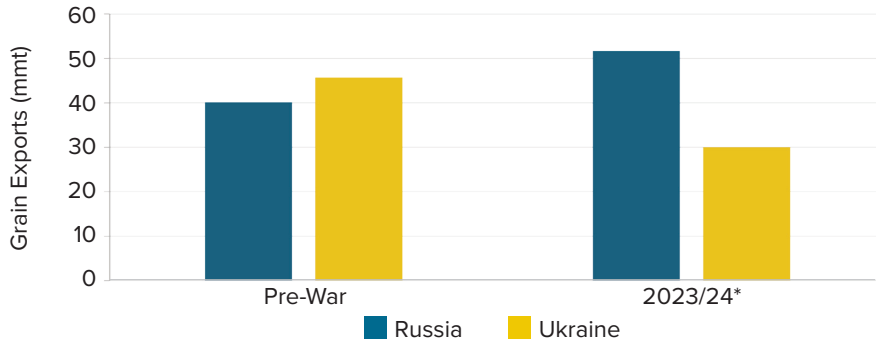
Blaming his decision on nonexistent export restrictions that were allegedly imposed by the West, Vladimir Putin has backed out of a trade deal brokered by the United Nations and Turkey that permitted Ukrainian grain to be exported from ports on the Black Sea to world markets. Putin is now trying to diminish Ukraine's ability to export grain, even though he has devastated Ukraine's 2023 harvest, reducing it by one-third. The Black Sea is now part of the war zone. This threatens the viability of all Black Sea grain exports, including grain sourced from Russia, with severe implications for global food security.

The Russia-Ukraine War has spooked world corn and wheat markets. Russia is the world's largest exporter of wheat, the most widely cultivated food crop. Wheat is used mainly in foodstuffs, including bread, pasta, biscuits, and cakes. Russia accounts for about 18% of global wheat exports, but unlike in the case of wheat, Russia is not a major player in the world corn market, supplying less than 2% of global corn exports.

Alternatively, Ukraine is not one of the top players in the wheat market. Ukraine provides 9% of the world's wheat exports and 14% of its corn exports and ranks as the fourth largest corn exporter, behind the United States, Brazil, and Argentina. Why are these trade statistics vital? The simple answer is that Russia's aggression in the Black Sea region increases the risk of the world grain market losing the number four corn exporter and the number one wheat exporter if grain vessels on the Black Sea become targets of drone strikes. In the worst-case scenario, grain exports shipped across the Black Sea and through the Bosphorus Strait (connecting the Mediterranean Sea and the Black Sea) could be halted, cutting off 27% (17%) of global wheat (corn) exports from Russia and Ukraine combined.

Figure 1 summarizes shifting volumes of Ukrainian and Russian

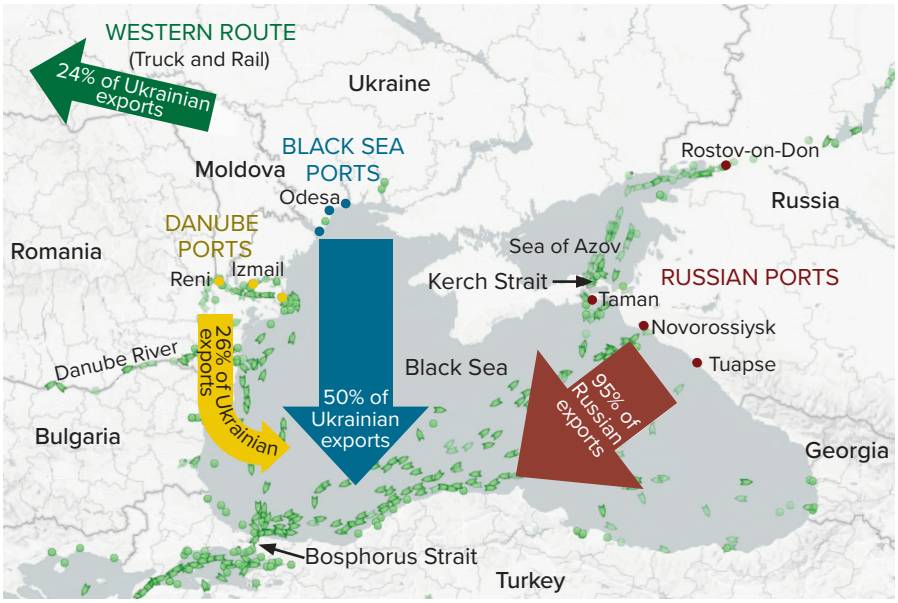
Figure 1. Russian Grain Export Fortunes Are Ukraine's Misfortunes



Source: Production, Supply, and Distribution Database (PS&D), United States Department of Agriculture. Available at: https://apps.fas.usda.gov/psdonline/app/index.html#/app/home.

Note: Grain exports, in million metric tons (mmt), include corn and wheat. Pre-war is the average for marketing years 2018/19 to 2020/21. The marketing year 2023/24* exports are projected. The corn marketing year is September to August, and for wheat it is July to June.

Figure 2. Black Sea Grain Export Routes and Volume



Source: The export shares for Ukraine were calculated based on data from the Ukrainian Grain Association (July 2022 to June 2023), while those for Russia are from the Foreign Agricultural Service (July 2022 to April 2023). The green cargo ship data are from MarineTraffic. We show ship positions and movements as of August 5, 2023.

grain exports (including corn and wheat) since the beginning of the Russia-Ukraine War in February 2022. These data show a three-year average pre-war period (2018/19–2020/21) versus the war period (2023/24). Before the war, Ukraine was a more significant exporter of grain than Russia—45.7 million metric tons (mmt) versus 40 mmt. However, in crop year 2023/24, when the full effects of the war are revealed, Russian grain exports (52 mmt) are expected to be over 70% higher than Ukraine exports (30 mmt). As a result of the war, Russian grain exports have surged, while Ukrainian exports have been suppressed.

Russian Aggression Caused Grain Price Spikes and Raised Market Volatility

The Russian invasion of Ukraine in February 2022 caused the commodity futures markets to explode, with significant jumps in the prices and volatilities of energy and grains. The war also stoked the most sizeable food security concerns since the 2007/08 commodity price boom. After the war in Ukraine broke out, the *Economist* wrote, "An unprecedented food crisis is engulfing the world—supercharged by the war in Ukraine. It has brought rising food prices, malnutrition, and the potential for much worse." The *Wall Street Journal* and the World Bank echoed this narrative.

On the Chicago grain futures market, wheat prices rose by 30% in March 2022, an extraordinary price jump in one month when there were no other unusual news events. At the same time, corn prices went up by 13%. Interestingly, wheat prices responded more than corn prices, even though Ukraine is relatively more important in the corn trade than in the wheat trade. However, almost all grain exports from Ukraine and Russia are loaded on vessels that cross the Black Sea and sail through Turkey's Bosphorus Strait to world markets (see the bottom left-hand corner of Figure 2).

If the war were to jeopardize all the grain shipments on the Black Sea, the wheat market would be hit harder than the corn market because the volume of wheat shipments on the Black Sea was about 1.7 times the corn shipments. Figure 2 shows that over 95% of Russia's grain exports are via the eastern portion of the Black Sea, and the largest ports are Novorossiysk and Taman. Ports in the Sea of Azov also export considerable amounts of grain through the Kerch Strait and then into the Black Sea. The war has periodically halted shipments through the Kerch Strait.

A second war-related price spike in corn and wheat occurred in July 2023 when Russia backed out of the Black Sea Grain Initiative (BSGI) and, at the same time, stepped up attacks on Ukraine's export infrastructure with the bombing of Odesa and Danube River ports. The BSGI, brokered by the United Nations and Turkey, allowed Ukraine to export grain through the Black Sea ports. In Figure 2, we see from the lack of ships in the northwest portion of the Black Sea that the Odesa grain ports stopped operating after the BSGI was terminated. Instead, bulk carriers are bunched up at the mouth of the Danube River, picking up grain at the inland Danube ports (e.g., Izmail and Reni), across the river from Romania (a NATO member), and then sailing back out to the south-western Black Sea.

After the July 2023 BSGI shock, wheat prices increased by 15% and corn prices increased by 10%, although prices reversed in less than two weeks. Besides looking at futures prices, it is also informative to consider how the market priced in the added uncertainty brought on by the war. We can use something called implied volatility to measure the war premium. Implied volatility can be measured in the corn and wheat options markets.

The Chicago corn and wheat markets are the world's central grain markets, trading futures and options. The futures contracts are obligations to buy or sell a specific quantity and quality of wheat or corn at a certain price on a specified future date, such as December. Alternatively, options give the buyer the right to buy or sell a futures

contract, but unlike futures, there is no obligation.

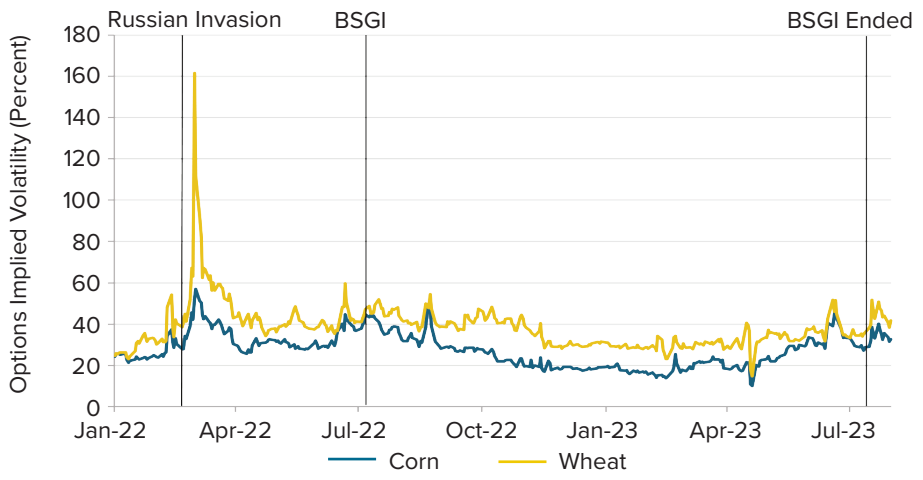
Implied volatility is a term used in the context of options trading, referring to the market's expectation of the future price volatility of the underlying asset, such as corn or wheat. One can think of implied volatility as the market's measure of expected risk (or expected volatility) of price changes embedded in options prices. Implied volatility is reported on a one-standard deviation annualized basis. This means that if the implied volatility is 50%, then the options market implicitly estimates that a one standard deviation change in the underlying price over the next year could lead to a ± 50% change in the current price. When implied volatility is high, the market participants expect significant price swings in the underlying commodity.

The time paths of nearby call options implied volatilities for the Chicago corn and wheat markets are shown in Figure 3. When Russia first invaded, the wheat implied volatility jumped from around 40% to over 160%. During the same period, the implied volatility for corn increased from about 25% to close to 60%. Then, over a year later, when Russia backed out of the BSGI, wheat volatility rose from 40% to 50%, and corn volatility went from 30% to close to 40%. Once again, the wheat market priced in a higher war premium than the corn market.

Black Sea Grain Initiative and Solidarity Lanes Lowered Grain Prices

After the February 2022 invasion, the so-called Solidarity Lanes were established on the border between Ukraine and the European Union (EU) and allowed for Ukraine grain exports via road, rail, and the Danube River ports. The Solidarity Lanes predated the BSGI, and both were successful in allowing Ukraine's agricultural exports to reach world markets, lowering world grain prices, and averting a global food security crisis. The original BSGI agreement was established on July 22, 2022, and was set for 120 days, but several extensions were granted. Unfortunately, before Russia withdrew from the deal in July 2023, Ukraine's grain exports from Black Sea ports had already slowed because Russia was dragging its heels on inspections of outbound ships, and Ukrainian grain production had fallen significantly due to the war.

Figure 3. Chicago Corn and Wheat Implied Volatility



Source: Bloomberg Terminal.

Note: The figure shows nearby call options implied volatility for corn and soft red wheat (SRW).

Ending the BSGI Could Backfire for Russia and Further Harm Low-Income Countries

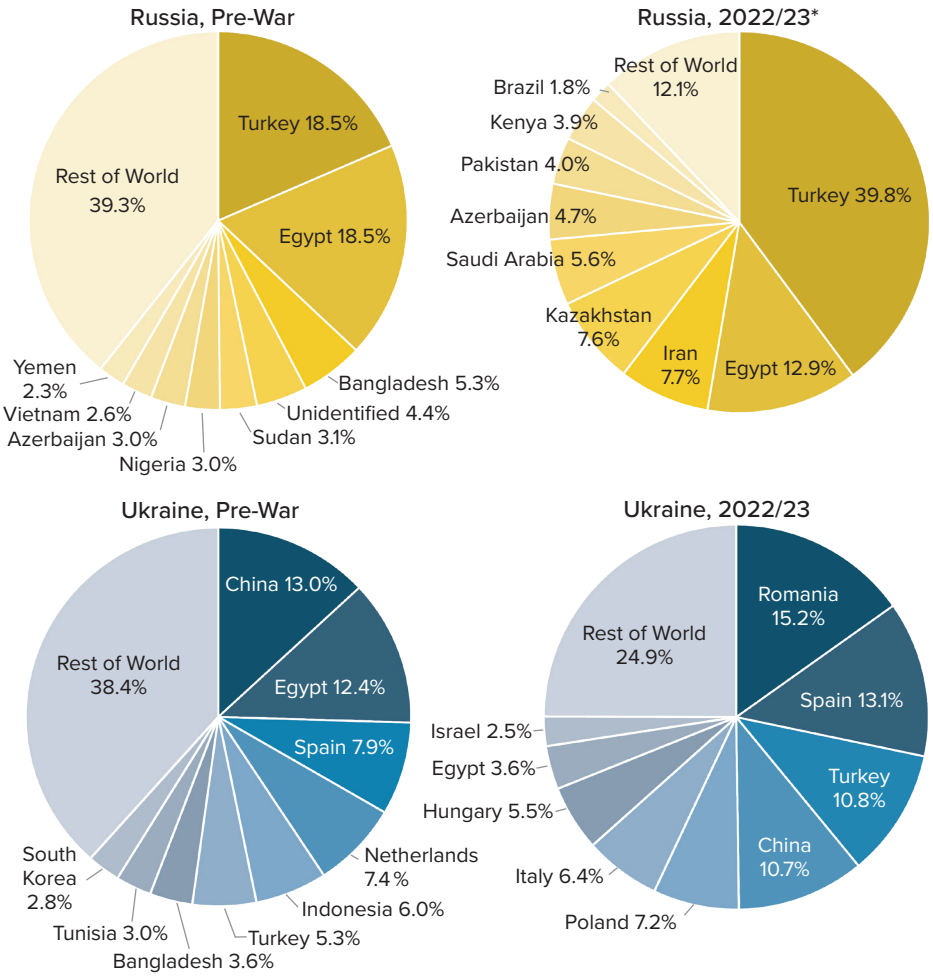
The BSGI allowed Ukraine to export almost 33 mmt of grain and other food via its Black Sea ports. Russia repeatedly complained that the deal benefited developed countries more than developing countries. However, an examination of the international trade statistics for the 2022/23 marketing year reveals that more than 50% of the grain from Ukraine went to developing countries, a marked increase from the pre-war period.

Before the war, the Ukrainian Black Sea ports could handle up to 4.5 mmt monthly. The maximum monthly grain shipments through those ports were less than 3.8 mmt under the BSGI. Ukraine also has the capacity to ship up to 2 mmt per month by rail and truck via the western route and up to 2.5 mmt via the Danube inland ports. The recent damage at those inland grain terminals by Iranian-made drones and cruise missiles launched by the Russians will further hinder Ukraine's ability to get its grain to market. The European Commission expects the Solidarity Lanes to handle up to 22 mmt in the current crop year, falling short of the 2023/24 expected Ukrainian corn and wheat harvest, which totaled about 42.5 mmt—30 mmt of which would be available for export.

Figure 4 (on page 4) compares the top 10 Russian and Ukrainian grain export destinations, by volume, before and after the Russian invasion. In the top panel, we show that Russia's grain exports to Bangladesh, Sudan, and Nigeria were diverted elsewhere after the war started. Turkey's imports from Russia increased significantly, and presumably, these imports were re-exported to other countries but with added costs.

In the lower panel, we find that Ukraine's grain exports to Egypt, Indonesia, and Bangladesh have been diverted during the war. More grain from Ukraine is being sold into Roma-

Figure 4. Global Grain Trade Reshuffle Harms Low-Income Countries



Source: All trade data comes from the Trade Data Monitor (TDM).

Note: We used reported grain export data for corn and wheat from June to May for 2018/19 to 2020/21 to calculate the pre-war average market share of the top nine export destinations and the rest of the world. *We used mirrored trade data for Russia for the 2022/23 reporting year because Russia stopped reporting trade flows in February 2022. Because TDM has fewer reporters than partner countries, the rest of the world is smaller when using mirrored trade data.

nia, Turkey, and Poland and undoubtedly re-exported at a higher cost. It is likely that import costs for grain rose in places such as Egypt, Indonesia, and Nigeria, which depended on Black Sea grain shipments. Rising food prices affect developing countries disproportionately because food expenditures represent a higher share of household expenditures. The end of the BSGI creates instability and uncertainty in global food markets and increases food insecurity for vulnerable nations.

The Russian decision to further weaponize grain exports is likely to backfire. At the recent Russia-Africa summit in Saint Petersburg, Putin promised six of the African leaders at the summit 25,000–50,000 tons of free grain each in the coming months, sharing additional Russian profits from grain sales enhanced by the Russian-caused price spikes. This offer is ironic, considering the record grain harvest Russia expects and the severely diminished grain export potential of Ukraine. The recent Ukrainian naval drone attack on a Russian oil tanker in the Kerch Strait and a Russian navy ship in the port of Novorossiysk reveals the vulnerability of Russia's own Black Sea grain shipment routes during wartime. These attacks also threaten Russia's oil exports, as Novorossiysk exports about 1.8 million barrels daily.

Conclusion

The Western sanctions against Russia in response to the Russian invasion of Ukraine did not block grain exports from Russia, and therefore the Russian retreat from the Black Sea grain deal was nothing more than another form of Russian aggression towards Ukraine. Fortunately, the Solidarity Lanes successfully moved a large share of the 2022 Ukrainian harvest to world markets. Given the large drop in the expected 2023 crop in Ukraine and the operation of the Solidarity Lanes, going forward, grain traders may be less concerned about getting Ukraine's grain to export position than the possibility of the loss of Russian wheat exports on the Black Sea.

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For additional information, the authors recommend:

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The Bioeconomy to the Rescue

Gordon Rausser and David Zilberman

The bioeconomy, encompassing sectors such as agriculture and forestry, presents an arena where natural resources can wield a crucial influence on climate crises management. This article unveils various burgeoning biotechnological strategies geared towards mitigating and adapting to climate change, with a view to enhancing environmental quality and human welfare.

The urgency to address the climate crisis has become a global policy priority. Despite international endeavors such as the Kyoto Protocol and the Paris Agreement, current greenhouse gas emission control measures have shown minimal success. Although these policy efforts have stimulated growth in solar and wind power sectors, as well as the electric vehicles industry, the chances of maintaining average global temperature rise below pre-industrial levels appear slim. Traditional decarbonization mechanisms primarily utilize principles of chemistry and physics within industrial contexts. However, the world has become increasingly aware of the bioeconomy's potential to significantly contribute to decarbonization, climate change mitigation, and adaptation. The bioeconomy encompasses sectors of the economy that employ renewable natural resources and living organisms to generate goods and services. Beyond climate change solutions, the bioeconomy has the potential to address other societal needs such as enhanced food security, increased biodiversity preservation, and reduced pollution.

The Bioeconomy

The bioeconomy combines technology and natural resources to produce a wide range of goods and services. The role of the traditional bioeconomy, reliant on animal power and fermentation for food preservation and production, is deeply woven into human history. With advancements in life sciences, starting with the discovery of DNA structure and the ensuing modern biotechnologies, a broad spectrum of opportunities has emerged. Modern medicine utilizes these biotechnologies to develop new drugs, and genetic engineering formed the basis for developing the vaccine for the COVID-19 pandemic. The agricultural biotechnology sector has significantly increased supplies of corn, soybean, and cotton.

Yet, the use of biotechnology remains curtailed by regulatory constraints, resulting in different governing bodies having different definitions and policies surrounding the bioeconomy. For example, the European Union has imposed stringent restrictions on the use of biotechnology—including genetically modified organisms (GMO) and clustered regularly interspaced short palindromic repeats (CRISPR)— and subscribes to a minimalistic definition of the bioeconomy. In contrast, countries such as Argentina, Brazil, the United States, and Canada perceive modern biotechnology as an essential element of their bioeconomy.

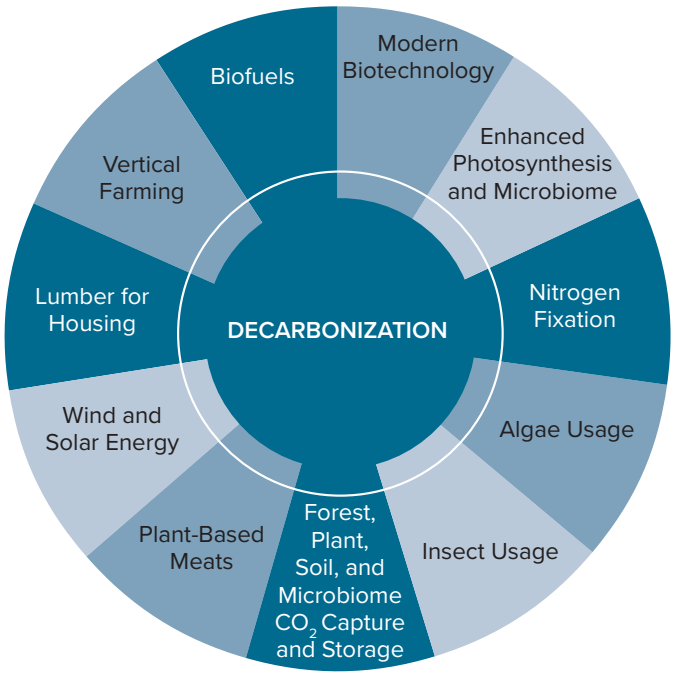
We define the bioeconomy as a sector leveraging contemporary life science knowledge and technology to use renewable natural resources for food, fuel, chemicals, pharmaceuticals, and other product manufacturing. Within this framework, agriculture provides much more than food production, and the bioeconomy is critical to transitioning from a non-renewable to a predominantly renewable resources-based economy. We emphasize the bioeconomy's circularity, highlighting the development of technologies where waste products serve as inputs for other processes—for example, technologies that convert animal wastes into food or energy products.

Bioeconomy Strategies for Decarbonization and Adaptation to Climate Change

The bioeconomy possesses the potential to catalyze decarbonization by promoting renewable, greener fuel resources, mitigating greenhouse gas (GHG) emissions from agriculture, and providing pathways for carbon sequestration. The bioeconomy's capacities can be harnessed to adapt to shifting climatic conditions, including rising sea levels, fertile land degradation, and increased susceptibility to extreme weather conditions. Several strategies can be employed to meet these challenges within the lens of the bioeconomy. The opportunities for such strategies are represented in Figure 1 (on page 6).

First, the introduction and assimilation of modern biotechnologies are essential, notwithstanding regulatory constraints. Empirical evidence supporting the benefits of GMOs is abundant and documents their potential to boost yields, minimize pesticide use, augment farmer profitability, reduce GHG emissions, and conserve land. Many developing countries have limited technology and infrastructure, and transgenic crops (plants that contain a gene or genes that have been artificially inserted) offer increased yields in the face of climate variations and pests. Preliminary research indicates that gene editing technologies could bring about more precision and supplementary agricultural management options, possibly expediting the development and introduction of new varieties.

Figure 1. The 11 Bioeconomy Strategies for Decarbonization



Source: Rausser and Zilberman. 2022. "Resource Economics and Modern Science to the Rescue." Available at: https://bit.ly/3QlKnUy.

However, stringent restrictions and costly, time-consuming regulations have confined the use of these biotechnologies primarily to major field crops, where large corporations dominate. Consequently, fruits, vegetables, and agricultural livestock have been subject to limited application of modern biotechnologies. The financial losses from current biotechnology regulations are estimated to be in the tens of billions of dollars, as numerous transgenic and CRISPR innovations went (or have gone) undeveloped or uncommercialized due to prohibitive regulatory costs.

The introduction of science-based technologies that balance benefits with risks, while reducing regulatory uncertainty, is likely to unlock these potent tools' full potential. Prior research suggests that the broad-scale adoption of existing transgenic crops like corn and rice could significantly reduce land use, lower food prices, mitigate food-security issues, and allocate more land for chemical and biofuel production within the bioeconomy. Coupling modern biotechnology tools with traditional agricultural practices could broaden the scope of solutions and expedite climate change adaptation. As climatic changes will require ongoing modifications to crop varieties and agricultural practices, developing the bioeconomy to leverage modern biotechnology tools will be crucial.

Second, photosynthesis productivity enhancement is a key strategy. Photosynthesis, the process that combines sunlight, carbon dioxide, water, and nutrients to generate plant material, can be optimized through biotechnology innovations. Studies show that through deeper roots and enhancing the soil microbiome, yield may be increased up to 20% or more, while also enhancing soil carbon storage.

Third, nitrogen fixation has significant potential. New research has found microbes that have the capacity to transform cereal crops like rice and corn into nitrogen-fixing crops. Nitrogen fixation could account for up to 80% of plant nitrogen uptake. Some market products propose using bacteria to replace 20% to 25% of required nitrogen, which could enhance agricultural productivity and reduce GHG emissions significantly, given nitrogen production's role as a major GHG emitter.

Fourth, algae can be harnessed as a source of food, fine chemicals, and energy. Macro- and microalgae have long been used for food and fine chemicals, like agar and beta carotene. However, new biological tools and research capabilities suggest numerous additional algae applications, such as protein, complex sugar, lubricant, plant biostimulant, and medicine sources. Algae offers considerable carbon sequestration potential, yet further research is required to understand the management of algae varieties for carbon storage, as well as the storage's magnitude and quality.

Fifth, insects represent a significant potential food source, particularly for protein. As protein prices rise with income growth, finding alternative protein sources has become a priority. Innovative methods are being developed to utilize insects, such as the black soldier fly whose larvae contain high protein levels. Notably, black soldier flies can feed on waste products, including food, plant, and animal waste, yet their larvae remain safe and edible following appropriate treatment.

Sixth, carbon sequestration can be accomplished via trees, soil, and plants. Trees and other vegetation sequester carbon through photosynthesis, store it within their roots, and transfer it into the soil. The potential exists to augment the United States' carbon sequestration capacity by 20% through the replacement and replanting of all unproductive forests. Large-scale global reforestation could notably decelerate global warming.

The adoption of low tillage agriculture has already diminished GHG emissions and fostered carbon

sequestration. Numerous technologies, including biochar, pyrolysis, cover crops, and other methodologies, can enhance soil carbon storage, increase crop productivity, and yield additional benefits. In particular, the employment of cover crops and composting can boost productivity and lead to significant GHG emission reductions as well as carbon production and sequestration.

Seventh, plant-based meats have the potential to reduce reliance on the production of animal meats that inefficiently convert feedstocks and also emit substantial GHG emissions. Theoretically, leveraging improved biotechnology knowledge to directly convert plant material into meat could potentially reduce GHG emissions. Several plant-based meat substitutes are already commercially available, and more are forthcoming. However, strides must still be made regarding product quality and consumer acceptance. Should the plant-based meat industry secure a significant portion of the meat market, the resulting GHG emission reductions could be substantial.

Eighth, solar and wind power are increasingly significant energy sources; however, they require large land areas. Often, agricultural regions are best suited for solar energy storage, potentially removing agricultural land from production, or necessitating new co-management strategies for solar energy and crop production.

Ninth, replacing concrete and steel with lumber in housing would decrease GHG emissions and facilitate the storage of embodied GHGs in the lumber. The lumber industry is innovating more resilient wood products, and biotechnology may allow for the customization of wood products for specific needs. While knowledge is rapidly expanding for building high-rise buildings with lumber, there is room for further research.

Tenth, vertical farming systems where plants are grown indoors, layer by layer, using LED lighting and controlled growth and nutrition systems can significantly increase yield and minimize the use of pesticides and other chemicals. Given the high infrastructure costs, vertical farming can be energy-intensive, thus requiring reliance on renewable energy sources to contribute to decarbonization. Vertical farming can enhance the production of high-value crops and promote a greener, healthier diet while reducing GHG emissions. However, its application remains limited and has yet to achieve economic scale.

Eleventh, second-generation biofuels offer the potential for broader adoption of biofuels and greater effectiveness of this technology. The biofuel sector presently provides around 5%

Table 1. The Impact of Biotechnologies on Various Objectives

Technology	Enhancing Agricultural Productivity	Enhancing Agricultural Resilience	Reducing Greenhouse Gas Emissions	Carbon Sequestration	Enhancing Biodiversity	Enhancing the Well-Being of Rural Sectors
Use of Modern Biotechnology	+++	++	++	+	0	++
Enhanced Productivity of Photosynthesis	++	+	+	+	+	++
Nitrogen Fixation	+	+	+++	+	0	++
Use of Algae	+	+	+	+++	+	0
Use of Insects for Protein and Waste Control	+	+	+	0	+	+
Sequestration of Carbon Through Soil and Forest	0	+	+	+++	+	+
Plant-Based Meats	+	+	++	0	+	0
Wind and Solar Energy	0	0	+++	0	0	+
Lumber for Housing	+	+	+	++	0	+
Vertical Farming	+	+	++	+	0	+
Biofuels	+	0	+	+	0	++

Source: Rausser and Zilberman. 2022. "Resource Economics and Modern Science to the Rescue." Available at: https://bit.ly/3QlKnUy.

of transport fuel consumption. Certain biofuels (e.g., sugarcane ethanol) contribute more to decarbonization than others (e.g., corn ethanol). However, biofuel GHG emissions tend to decline over time due to processing improvements, productivity increases, and reductions in feedstock-production GHG emissions.

The biofuel sector will likely specialize in producing aviation fuel and heavy vehicle fuel in the long term. Given the gradual diffusion of electric cars, biofuels may play a major role in passenger transportation during a transitional period. So far, second-generation biofuels have not been widely used, but they have demonstrated significant potential in recent studies. Once technological production barriers are overcome, they may play a significant role.

The Impact and Likelihood of These Strategies

We have presented 11 approaches through which the bioeconomy can contribute to decarbonization and adaptation to climate change. However, these strategies can also serve additional societal objectives, such as increasing agricultural productivity, enhancing resilience and biodiversity, and improving the well-being of the agricultural sector.

Table 1 (on page 7) illustrates how each approach contributes toward achieving a specific objective. A scale is used where 0 denotes no contribution, + signifies a minor contribution, ++ implies a moderate contribution, and +++ represents a major contribution. Based on this scale, agricultural biotechnology is hypothesized to contribute across all categories, while algae culture predominantly contributes to carbon sequestration, the utilization of solar and wind energy predominantly contributes to the reduction of GHG emissions, and biofuel production predominantly contributes to impacting the rural sector.

The bioeconomy strategies discussed should not exist in isolation, but rather as complements to other strategies. These include the use of geothermal energies, battery energy storage, improved air conditioners and microgrids, and nuclear energy, all aimed at addressing climate change challenges.

The aforementioned approaches are still in their early stages. To formulate an effective selection and integration strategy, mechanisms must be established where scientists can offer some assurance regarding the scalability of each technology in terms of volume and cost reduction. Policymakers must promote policies and initiatives that stimulate investment in these alternatives. The implementation of each initiative necessitates an intelligently designed supply chain that hinges on public-private collaboration and entrepreneurship.

Possible strategies may encompass incentives such as carbon pricing and tradable permits, research and development support, and potentially credit subsidies and/or mandates. Policy design should consider economic efficiency as well as economic feasibility. Public education and outreach activities are also integral to enhancing public acceptance of certain solutions and increasing awareness of the trade-offs in addressing climate change. Agricultural and resource economists are well-placed to spearhead a multidisciplinary research agenda, identifying promising decarbonization and agricultural development strategies, proposing policies to foster their development, adoption, and acceptance, and developing tools for supply chain management.

Conclusion

The climate crisis is a global issue; changes within California and the United States alone will not sufficiently mitigate or reduce the associated damage. A worldwide effort is required that strikes a balance between curtailing GHG emissions and improving quality of life.

The concept of a bioeconomy is inherently global. Although the new bioeconomy will develop within California, it is crucial to recognize that the state is expected to develop solutions that can be globally implemented. The advantages of introducing a bioeconomy in California extend beyond the state's borders, benefiting the nation and the world. The University of California can provide the intellectual groundwork for the bioeconomy, and UC Agricultural and Natural Resources should prioritize its embedded strategies.

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For additional information, the authors recommend:

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Zilberman, David, Alison L. Van Eenennaam, Felipe De Figueiredo Silva, and Josephine F. Trott. 2021. "The Costs of Overregulating Animal and Plant Biotechnology: Lessons from COVID-19." *ARE Update* 24(4): 1–4. Available at: https://bit.ly/3ayavpe.

Economic and Pest Management Evaluation of the Proposed Regulation of Nitroguanidine-Substituted Neonicotinoid Insecticides: Six Major California Commodities

Yanan Zheng, Rachael Goodhue, Kevi Mace, Jess Rudder, Tor Tolhurst, Daniel Tregeagle, Hanlin Wei, Beth Grafton-Cardwell, Ian Grettenberger, Houston Wilson, Robert Van Steenwyk, Frank Zalom, Monique Rivera, and John Steggall

The California Department of Pesticide Regulation (DPR) will implement a regulation restricting the use of nitroguanidine-substituted neonicotinoid (NGN) insecticides on January 1, 2024. Developed to protect managed pollinators, the regulation includes three key features: 1) timing restrictions, 2) cumulative per-season use rate restrictions when multiple NGNs are used, and 3) use restrictions on individual NGNs for crops deemed highly attractive to bees. Using economic data and pesticide use data from 2017–2019, we analyze the potential economic impact of the final draft of the regulation based on the net return losses for six crops: almond, citrus, cotton, grape, strawberry, and tomato. If the regulation had been in effect, the annual net return losses for the six crops considered would have ranged from $12.137 million in 2019 to $13.316 million in 2017.

Neonicotinoids are a class of systemic insecticides that attack insects' central nervous system, blocking nicotinic acetylcholine receptors. They are effective against many sucking and some chewing insects and have become widely used since their introduction in the mid-1990s as alternatives to organophosphates and carbamates. They have comparatively low toxicity to mammals but are toxic to many insects, including bees. California's Food and Agricultural Code (FAC) section 12838 required DPR to issue a risk determination report, which it completed in July 2018. The report detailed whether uses of four NGNs (clothianidin, dinotefuran, imidacloprid, and thiamethoxam) at full label rates on different crops are high risk or low risk to bees. For example, the report found that imidacloprid-treated citrus, cotton, strawberry, and tomato could pose a high risk to bees.

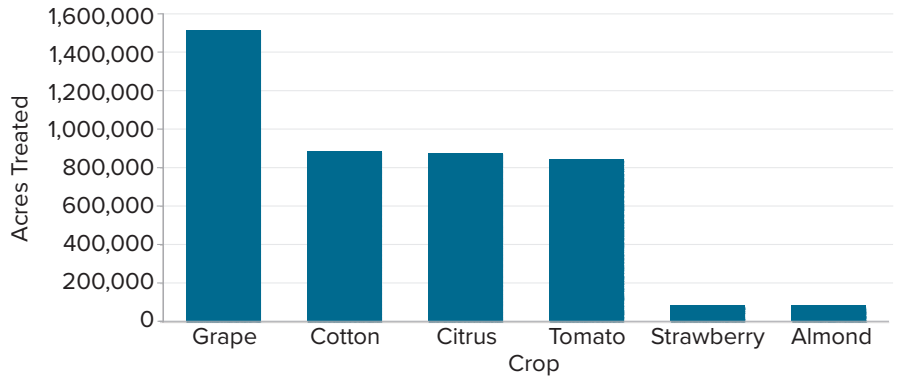
Under the January 1, 2024 regulations, NGN pesticide applications to all crops are prohibited during bloom. Citrus, stone fruit, and almonds, crops deemed highly attractive and routinely in contact with managed pollinators, are subject to additional restrictions on the cumulative pounds per acre for individual NGNs and cumulative applications of all NGNs annually, as well as restrictions on the times of year when NGNs can be applied. In other crops, including fruiting vegetables, walnuts, and berries, one NGN applied with one application method (soil versus foliar) may be used up to the cumulative amount specified on the label during a season. However, if a grower decides to use more than one NGN or more than one application method, there are restrictions on the cumulative use rates that are lower than current labels allow.

Identifying Impacts on Six Major Crops

This study uses economic data and pesticide use data from 2017–2019 to estimate the economic and pest management implications of the final draft of the proposed regulation for six crops: almond, citrus, cotton, grape, strawberry, and tomato. These crops accounted for 54% of the value of California's field crop, fruit, nut, vegetable and melon production and 57% of its agricultural exports in 2021. Total acres treated with target NGNs for each crop over the three-year period 2017–2019 are plotted in Figure 1 using DPR's Pesticide Use Report (PUR) database.

Net return losses occur if gross revenues decline as a result of decreased yield or if costs increase. For these six crops, the net return loss is due entirely to cost increases because no yield losses are anticipated due to the proposed restrictions. We estimate the change in pest management costs due to the regulation's restrictions on NGN applications. For applications that would have been prohibited, we estimate the change in pest management costs for each crop based on the acres

Figure 1. Total Acres Treated With NGNs by Crop (2017–2019)



Source: DPR Pesticide Use Report (PUR) database.

Table 1. Estimated Changes in Costs by Crop and Year ($ Millions)

Crop	2017	2018	2019
Almond	0.012	0.002	0.006
Citrus	2.917	3.063	2.968
Cotton	1.811	1.155	1.653
Grape: Raisin and Table	0.692	0.488	0.223
Grape: Wine	1.499	1.446	1.634
Strawberry	0.200	0.208	0.209
Tomato: Fresh Market	1.240	1.133	1.091
Tomato: Processing	4.945	5.650	4.353
Total	**13.316**	**13.144**	**12.137**

Source: Authors' calculations.

treated, the available alternatives, the cost of any change in the application method, and the costs per acre of the active ingredients (AIs).

The baseline total cost is established by multiplying the cost per acre for each target NGN by the acres treated with that target NGN for all applications that would be prohibited. This is compared to the cost of the regulated scenario. In the regulated scenario, we assign all the acres that had been treated with the target NGNs in prohibited applications to alternative AIs in proportion to the acreage treated with the alternative AIs. For example, if one NGN and two alternative AIs, pesticide A and pesticide B, were used on 100, 100, and 200 acres of almond, respectively, pesticide A would be used on 33 acres (33.33%) and pesticide B on 67 acres (66.67%) of almond that had been treated with the NGN. Loss estimates do not include losses owing to the more rapid development of resistance to remaining AIs by pests for which NGNs are part of the current management program.

Cost Increases

Because the applicable restrictions are crop-specific, we present the estimated cost changes by crop (Table 1).

Almond

Almond was California's third largest agricultural commodity in terms of production value, ranked behind milk/cream and grapes. Gross revenues totaled $5 billion and exports were $4.6 billion in 2021. Clothianidin is the only NGN currently registered for use in almond production. The insects most commonly targeted are leaffooted bug, stink bug, and San Jose scale. There are effective alternative AIs for each pest. The annual total cost increase to almond from the regulation is estimated to be $0.012 million or less. The absolute value of the costs is negligible because very few almond acres were treated with NGNs, and the composite alternative costs were virtually the same as clothianidin.

Citrus

Citrus—specifically grapefruit, lemon, orange, mandarin, and their hybrids—constituted one of California's top ten most economically important commodities by value, with $2.5 billion in gross revenues and $932 million in exports in 2021. NGNs are used to manage Asian citrus psyllid (ACP), citricola scale, citrus leafminer, Fuller rose beetle, and glassy-winged sharpshooter. Two NGNs are registered for California citrus: imidacloprid and thiamethoxam. Applications for ACP, a quarantine pest, are exempt from the proposed regulation. Without the use of imidacloprid, the deadly bacterial disease vectored by ACP, huanglongbing (citrus greening disease), would spread at a faster rate in the state, jeopardizing the entire industry. Setting aside quarantine applications, there would have been a cost increase of 61.6% to 66.6% for other applications to control the remaining target pests, corresponding to an annual total cost increase of $2.917 million to $3.063 million. The cost increases were driven mainly by the higher cost of the composite alternative: total cost per acre would rise by $34.02 (90.5%) on imidacloprid-treated acreage and $25.32 (54.7%) on thiamethoxam acreage.

Cotton

Cotton generated $468 million in gross revenues and $292 million in exports in 2021. All four NGNs are registered and used in cotton to target aphid, lygus bug, mite, thrips, and whitefly. The percent change in costs ranges from 28.8% to 36.6%, corresponding to an annual total cost increase of $1.155 million to $1.811 million to control the target pests. The magnitude of these changes was driven by the large acreage of treated cotton and the high material cost differences per acre between the most widely used NGN in cotton—imidacloprid ($22.04)—and specific alternatives—flonicamid ($37.01) and acetamiprid ($50.23)—that accounted for a large share of non-NGN treated acreage.

Grape

Grape was California's second largest agricultural commodity by production value, with gross revenues of $5.2 billion and exports totaling $2.2 billion in 2021. Growers use NGNs against grape phylloxera, leafhopper, sharpshooter, and vine mealybug. There are NGN alternatives that target leafhopper, mealybug, and sharpshooter, but they are more expensive. However, phylloxera management does not have good alternatives for NGNs. For table and raisin grapes, the percent change in costs on affected acreage ranges from 57.4% to 71.4%. The associated annual total cost increase to control the target pests is $0.223 to $0.692 million.

For wine grape, the percent change in annual total costs ranges from 72.0% to 73.8%. The associated annual total cost increase is $1.446 million to $1.634 million. The changes are driven mainly by the use rate restrictions on fields using more than one NGN or application method and the greater cost of alternatives.

Strawberry

In 2021, strawberry was California's sixth largest agricultural commodity by production value, with gross revenues of over $3 billion and exports of $475 million. Two NGNs are used to control sucking insect pests in strawberry: imidacloprid and thiamethoxam. Target insect pests include aphid, leafhopper, lygus, root weevil and grub, and whitefly. The use of thiamethoxam occurs after bloom has started, and blooming continues throughout the harvest season. Consequently, all applications of thiamethoxam are considered prohibited and would be replaced with alternatives. In contrast, almost all imidacloprid use occurs before bloom, so, all imidacloprid applications are considered allowed. The proposed regulation results in an estimated $0.2 to $0.209 million increase in annual total cost, which is a 29.2% increase in costs to control the target pests on acres treated with thiamethoxam.

Tomato

Tomato was California's ninth largest commodity by production value in 2021, with gross revenues of $1.2 billion and exports of $692 million. California is the largest producer of processing tomato in the United States and the second largest producer of fresh tomato. NGNs are used for aphid, flea beetle, leafhopper, leafminer, lygus, potato psyllid, stink bug, thrips, and whitefly. As systemic pesticides, the NGNs can be applied once at planting and provide effective control for an extended period of time. Without them, growers would likely need to apply multiple applications of alternative AIs, greatly increasing the treatment cost on affected acres. Our estimates show there would be a 150.5% to 186.6% increase in annual total treatment costs for fresh tomato and a 133.5% to 163.5% increase for processing tomato. In absolute terms, the annual total cost increase ranges from $1.091 million to $1.240 million for fresh market tomato and $4.353 million to $5.650 million for processing tomato to control the target pests.

Policy Implications

Over the three-year period (2017–2019), the six crops accounted for over 80% of NGN use in terms of both total acres treated and pounds of AI applied in treatments that would have been affected by the regulation (not all crops would be affected). Overall, the estimated annual net return losses for the six crops would have totaled $13.316 million in 2017, $13.144 million in 2018, and $12.137 million in 2019 if the regulation had been in effect (Table 1).

The crop-specific provisions are designed to mitigate the negative effects of NGNs on managed pollinators by reducing their exposure to NGNs. Many crops in California are dependent on managed pollinators, including almond, apple, avocado, cherry, cucumber, pumpkin, kiwi, melons (honeydew, cantaloupe, watermelons), beans (lima, blackeye, garbanzo), peach, nectarine, pear, plum, and sunflower. The 2019 value of these fourteen key crops dependent on pollination was $7.8 billion. The regulations also recognize that a targeted approach can enable some crops to maintain close to historical levels for the most critical uses, while other crops would see significant economic and pest management impacts.

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For additional information, the authors recommend:

Goodhue, Rachael, et al. 2021. "Economic and Pest Management Evaluation of Proposed Regulation of Nitroguanidine-Substituted Neonicotinoid Insecticides: Eight Major California Commodities." Prepared by OPCA CDFA; the University of California; and the UC Cooperative Extension. July 2, 2021. Available at: https://bit.ly/3EiS8mG.

Mace, Kevi, et al. 2022. "Balancing Bees and Pest Management: Projected Costs of Proposed Bee-Protective Neonicotinoid Regulation in California." *Journal of Economic Entomology* 115(1): 10–25.

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