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Implications of Climate Policy for Local Agriculture and Irrigation

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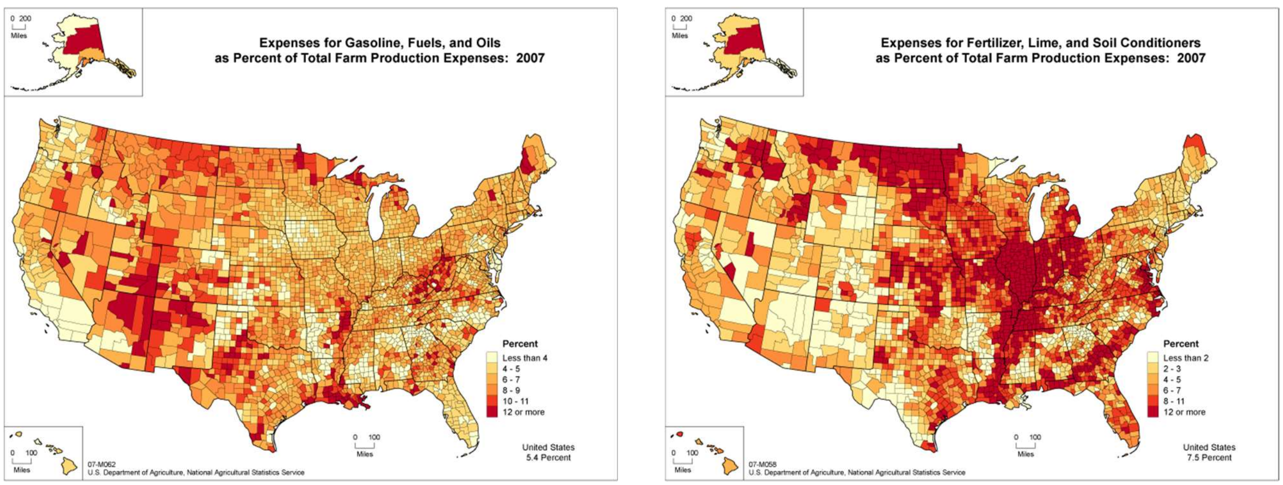
Abstract

A national carbon pricing policy will have implications for energy-intensive economic sectors. The transmission to agriculture can be through nitrogen fertilizer and irrigation as they are major energy-intensive inputs for agricultural production. The goal of this study is to quantify the impact of the United States carbon pricing policy on agricultural land use and irrigation water. A high-resolution partial equilibrium model of land use and water will provide the local and national responses. Specifically, the shocks are obtained from other studies based on the ENVISAGE model quantifying the change in the fertilizer and energy costs. Then, SIMPLE-G quantifies the likely changes in the spatial pattern of water and land use given the estimated shocks in input prices. This calculation entails grid-cell specific input shocks and heterogeneous economic responses.

1 Introduction

What are the implications of a national carbon policy for local agriculture? A national carbon pricing policy will change relative prices and the allocation of economic resources in a country. There is a vast literature on partial and general equilibrium impacts of such policies (Nordhaus and Yang 1996; Dellink 2005; Golub et al. 2013; Hafstead et al. 2018; Chepeliev and van der Mensbrugghe 2018; Fan, Kong, and Zhang 2018; Carbone and Rivers 2020). These studies have considered the inter-industry linkages and the cascading impacts of the national policy through input-output linkages. In addition, there are some efforts to look at the implications of national carbon policies for land use (Van Der Werf and Peterson 2009). This study contributes to the current literature by looking at irrigation and nitrogen fertilizer as two main channels of climate policy transmission to more than 75,000 agricultural production grid cells in the United States.

Due to the spatial heterogeneity in cost shares, the local implications of carbon policies are expected to vary spatially. Differences in the cost structure and energy intensity of farming will play a particularly important role. Figure 1 shows the share of fuel and fertilizer in total farm expenses by U.S. counties. The average share of fertilizer in farm expenses ranges from near zero to above 12% with significant spatial heterogeneity. The share of fertilizer in total cost is generally higher in the rainfed area (mainly in the Eastern US) than in irrigated areas (mainly in the Western US). The average share of fuels is also spatially heterogeneous but higher in irrigated areas.

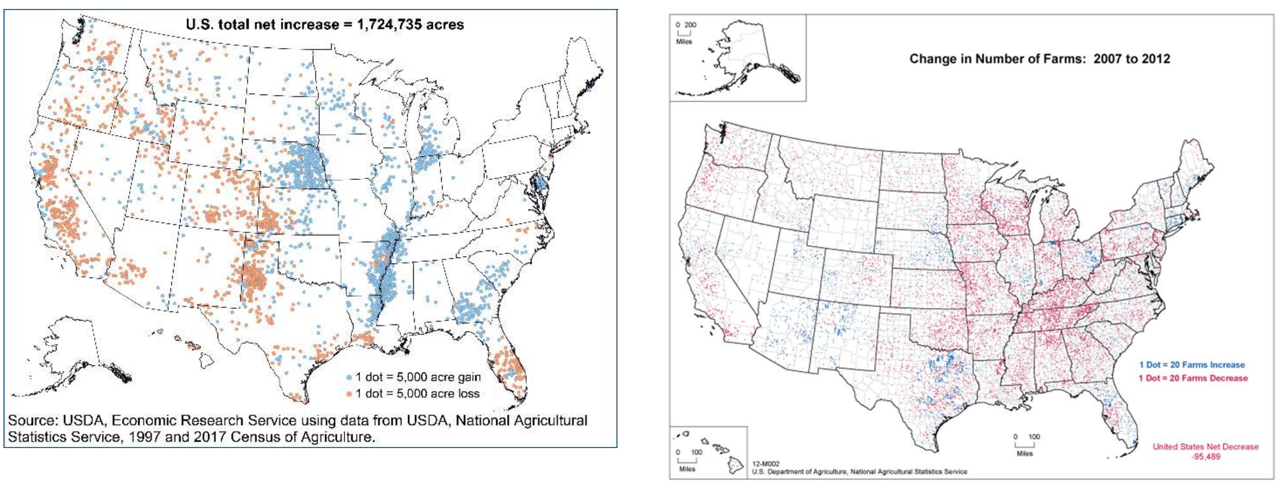


(a) Cost share of fuels (b) Cost share of purchased fertilizer

Figure 1. The share of fuels and fertilizer in total farm expenditure in 2007. Source: USDA.

While a simple accounting calculation may highlight the hotspots of local damages due to climate policy, it will be misleading for assessing the policy impacts. The main reason is that it ignores the farmers' responses to policy and the re-allocation of land and water resources across the landscape. Assuming a climate policy will correct the relative prices, some farmers and agents would be better off due to an increase in their profit margins. Some farmers have higher flexibility in substituting fertilizer and fuels and changing the scope of production. Thus a comprehensive quantitative analysis needs to take into account the cost shares as well as spatially heterogeneous elasticity parameters.

Another critical factor is the possibility of land conversion. As irrigated cropland will be affected differently from rainfed cropland, farmers may find that cropland conversion is more beneficial given the relative prices of fertilizer and fuels. Figure 2 illustrates changes in irrigated cropland acres and the number of farms based on the United States Department of Agriculture (USDA) Census of Agriculture. The observed conversion occurring due to market and hydroclimatic forces supports the idea of the possibility of cropland conversion due to climate policy.



(a) Change in irrigated acres 1997-2017 (b) Change in number of farms 2007-2012

Figure 2. The observed changes in irrigated acres and number of farms. Source: USDA.

To capture the major inter-industry linkages and spatially heterogeneous responses, this study integrates the results of a general equilibrium model within a partial equilibrium agricultural model. The agricultural model will take care of biophysical and economic determinants of local responses while connecting the local production to regional and global agricultural markets. It employs the county-level information from the USDA in the gridded model across the entire continental United States. Each grid cell has its own supply and demand parameters and production structure.

This study highlights the communities that will be affected the most and their likely responses to reduce the negative impacts on production. It also illustrates the gains to the grid cells benefiting from the spill-over effects. This can help inform local policies aimed at protecting the most vulnerable and affected communities. It can also help the research community in understanding the likely changes in the economic geography and relocation of activities.

2 Methods

This study considers four scenarios of unilateral carbon pricing ($50, $100, $150, $200) in the United States. Considering the economy-wide impact of such a policy, a general equilibrium framework is necessary to consider the likely changes in relative prices, sectoral activities, and trade. Also a gridded economic land use model is used to capture local economic responses.

2.1 The general equilibrium impacts

While there are many possible computable general equilibrium (CGE) candidates for this purpose, this study takes the outputs of ENVISAGE, the Environmental Impact and Sustainability Applied General Equilibrium Model (van Der Mensbrugghe 2018). The ENVISAGE Model is a general equilibrium multi-sector model designed to analyze a variety of issues related to the economics of energy policies and climate change. This model has been used recentrly for analysis of US climate policy (Baldos et al. 2022). For each pricing scenario, the final impact on the commodity prices is calculated. The commodities included in this study are ammonia, labor wages, natural gas, electricity, and petroleum products.

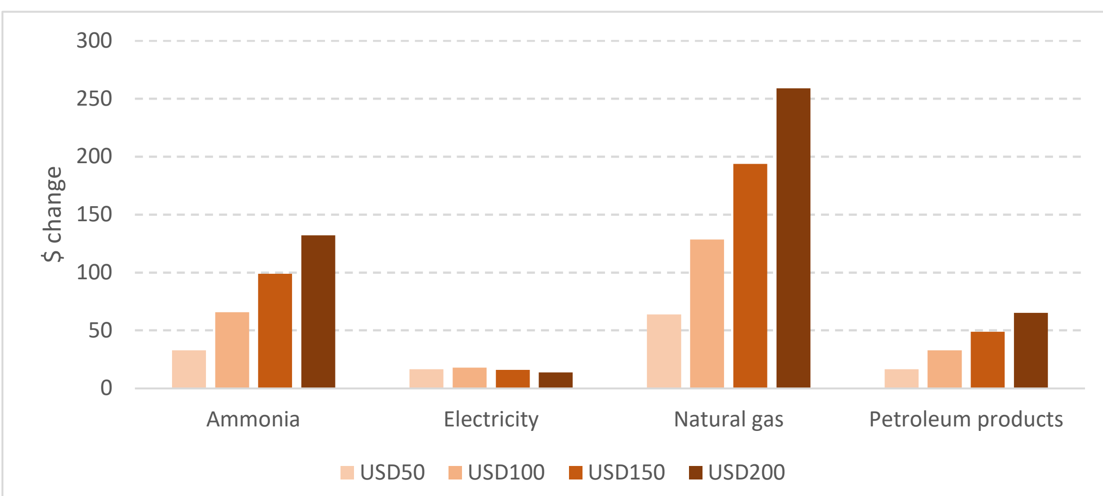


Figure 3. Impacts of U.S. climate policy on commodity prices. Source: Baldos et al (2022)**.**

2.2 Land use model

To capture the impact of carbon pricing on land and water use decisions, this study employs the SIMPLE-G-US-Allcrops model (Baldos et al. 2020). SIMPLE-G is a global partial equilibrium model for analyzing local agricultural production. While there are other versions of SIMPLE-G model (Liu et al. 2014; 2017; 2018; Haqiqi et al. 2020), the Allcrops-US is one of the best candidates for this analysis as it includes irrigation and nitrogen fertilizer inputs which are the most energy-intensive practices in agriculture. In addition, it is focused on the US and with all the crops involved, it will produce more precise spill-over effects. It also considers the spatial heterogeneity in the irrigation and fertilizer cost structures for more than 75,000 production units, each reflecting an individual grid cell (these 5 arc-min grid cells encompass around 6,000 to 7,500 ha). The demand for food is modeled at the national and regional levels. There are two crop production functions for each grid cell: irrigated and non-irrigated. Each production function is a nested constant elasticity of substitution (CES) combining nitrogen fertilizer, land, groundwater, surface water, irrigation equipment, and a composite index of other inputs. The input mix reflects both differences in production technology as well as crop composition. The model produces a grid-cell-specific commodity assuming the composite goods are differentiated across grid cells and US Farm Resource Regions. The model includes grid-specific land and water supply elasticities estimated empirically. An additive CET (constant elasticity of transformation) function governs the allocation of land between irrigated and non-irrigated practices based on Zhao et al. (2020). Finally, an Armington function determines the international trade of agricultural commodities. For more details, please refer to Baldos et al. (2020).

2.3 Other data

The energy cost shock for irrigated grid cells is calculated based on ENVISAGE results and gridded energy cost shares. Different information at the county and state levels (Figure 4) is integrated to estimate the energy cost share for each grid cell. Total energy cost shares at the county level are extracted from the 2017 USDA Farm Production Expenditures. The share of each energy commodity is obtained from the 2018 USDA Irrigation and Water Management Survey. The SIMPLE-G model is constructed based on various biophysical and economic information around the year 2017 (Haqiqi et al. 2022).

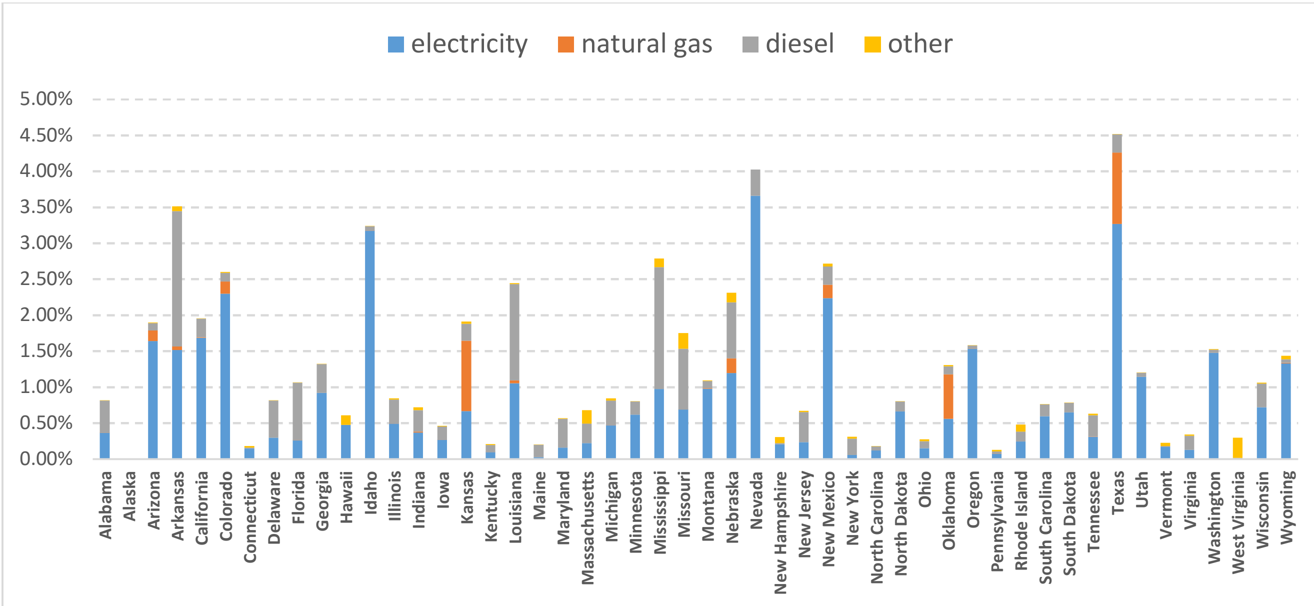
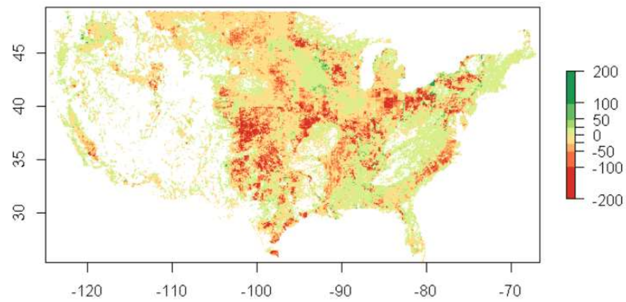


Figure 4. The average share of selected inputs in total sales by state, USDA, 2013.

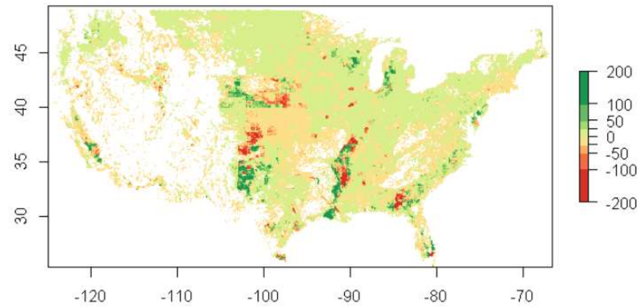
3 Results

This manuscript concentrates on the $100 carbon pricing policy affecting the costs of energy and ammonia which is used for shocking the costs of nitrogen fertilizer. Other scenarios will be discussed in the full paper. Figure 5 illustrates the equilibrium impact on cropland extent as a result of this policy. In the left panel, the red colors show the reduction in cropland area and the green colors show the increase in the cropland area in hectares per 5 arcmin grid cell. Overall, the US cropland is expected to slightly decline by 0.9%. However, the map shows a significant heterogeneity in responses ranging from -200 ha to +200 ha change in cropland area. The right panel shows the change in irrigated area. for the continental US, the model predicts a 0.7% increase in irrigated area.

We found that irrigated areas may decline in Texas, Kansas, and Oklahoma. This is not surprising due to a higher share of natural gas in the pumping energy mix in these states. Yet, there is a mix of negative and positive changes in these states



Change in total cropland

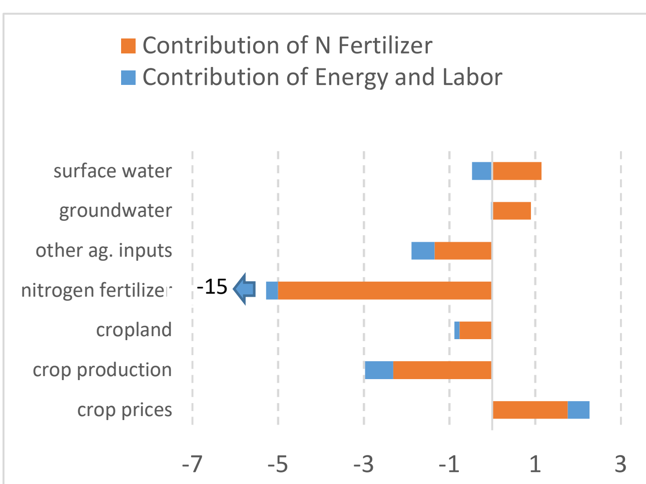


Change in irrigated cropland

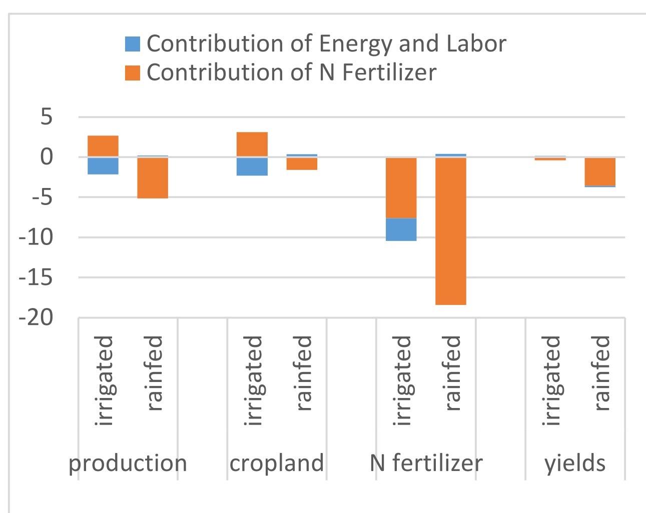
in ha per 5-arcmin grid cell

Figure 5. The impact of $100 carbon pricing in the US on total and irrigated cropland.

Figure 6 summarizes some of the major national indicators of US agriculture. As a result of this policy, the US average price of crop production increased by 2.3%, and production declined by 3.0%. The average application of nitrogen fertilizer decreases by 16.0% in response to the higher fertilizer costs. Groundwater withdrawals increase by 0.9% as the climate policy favors production in the more nitrogen-efficient irrigated areas. The increase in water withdrawal along with a decline in fertilizer application foreshadows an aggregate substitution from fertilizer to water at the national level. The right panel also shows a shift from rainfed to irrigated agriculture. Note that the figures also decompose the impact to show the contribution of changes in fertilizer costs and energy costs.



(a) Aggregate metrics



(b) Indicators by irrigated and rainfed

Figure 6. The impact of $100 carbon pricing in the US on national agricultural indicators

The surprising result is the increase in irrigated production as one would expect the irrigated production would be suffering from the increase in fertilizer and energy costs. However, the decomposition in Figure 6 reveals that the increase in costs of fertilizer could contribute to an increase in irrigated production. The decomposition approves the expectation that the contribution of the increased cost of energy would be a reduction in irrigated production. The appendix also decomposes the impacts of the $100 carbon price scenario on crop production and production costs for USDA Farm Resource Regions. Figure A-1 shows the boundaries of each Resource Region and Figure A-2 shows the impact on production level and costs. The findings suggest that there are opposing forces in the Western US (Fruitful Rim, Basin and Range).

The unexpected results are coming from the opposing forces and the need for computation to determine the dominant force (fertilizer costs vs energy costs) at each location and the overall market impact. To understand the model results, it is helpful to decompose the drivers of changes at each location into three components: local fertilizer costs, local energy costs, and national crop prices. In all the locations in green coloring in Figure 5, the impact on national crop price is dominant. In other words, the increase in national crop prices can cover the increase in local energy and fertilizer costs at some locations. While the increase in energy costs discourages irrigation, this is overwhelmed by the impact of the change in fertilizer costs which favors irrigated over rainfed production.

4 Conclusions

This paper introduces a framework to evaluate the impacts of national climate policy on local agricultural production. It involves a general equilibrium model to capture the inter-industry linkages and a gridded partial equilibrium model to capture the local land-use responses. This framework allows the analysis of the spill-over effect in a multi-scale setup.

The findings suggest that there are three main drivers of change at each location: local fertilizer costs, local energy costs, and the response to national crop prices. Depending on which driver is dominant, the production may expand or shrink. The cropland may decline in many rainfed areas as the production is not profitable with new fertilizer costs. The findings suggest that irrigation and water use may increase as a result of climate policy. This is due to the high cost of fertilizer in rainfed agriculture and the spillover effects from rainfed production and conversion to irrigated production.

Finally, the 16% reduction in fertilizer application as a result o $100 carbon pricing would have water quality benefits. The reduction in fertilizer application would significantly reduce the nitrate leaching into the water resources. So, improvement in water quality can be counted as a co-benefit of carbon policy for the United States.

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Appendix

This appendix summarizes the impacts of the $100 carbon price scenario on crop production and production costs for USDA Farm Resource Regions. The results are aggregated from irrigated and non-irrigated grid cells.

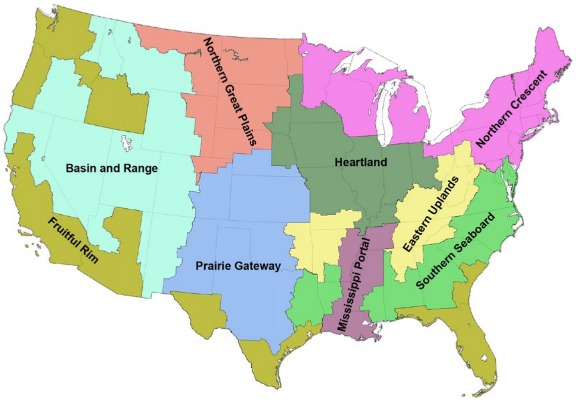

Figure A-1. USDA Farm Resource Regions

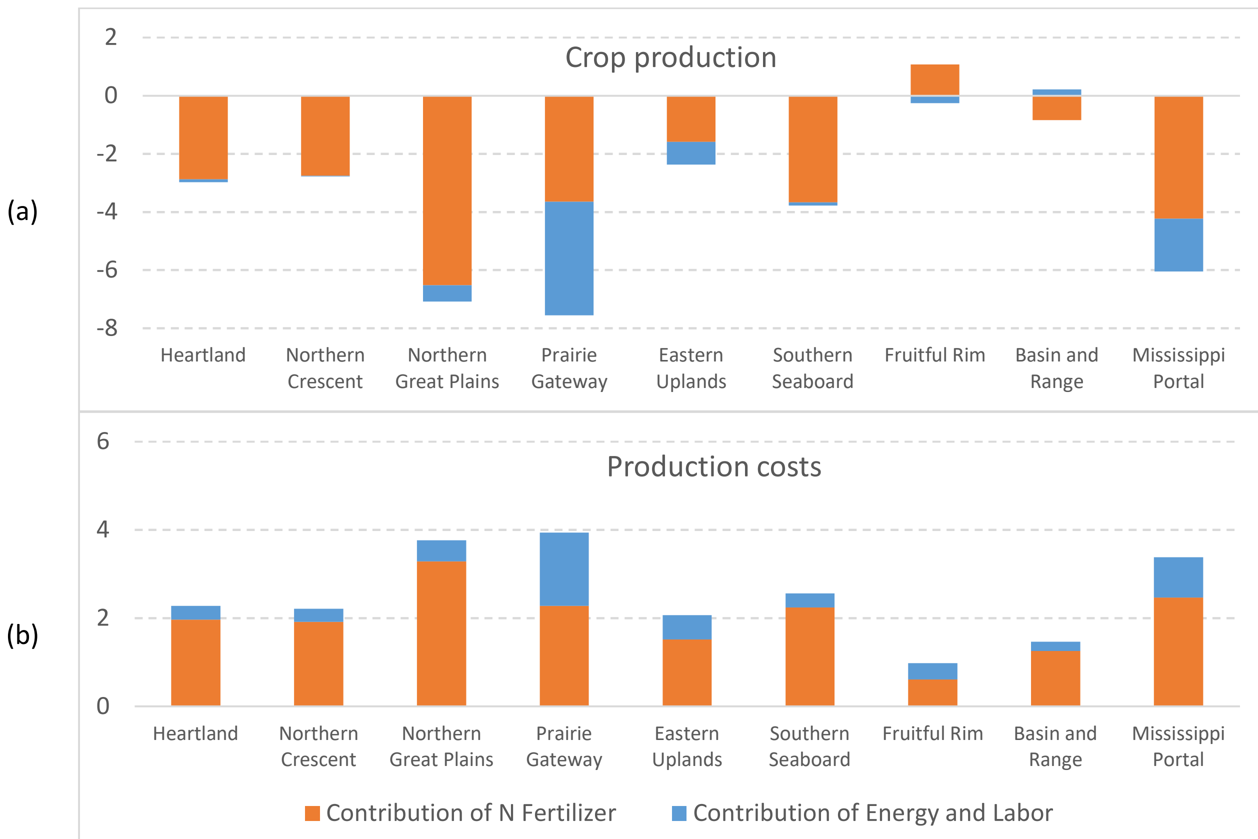

Figure A-2. The percentage change in crop production (a) and production costs (b) by USDA farm resource regions, (climate policy, USD100 scenario).