Bren School of Environmental Science & Management
University of California
Santa Barbara

The Effect of Climate Change on the Production Costs of the Dairy Industry in the United States

2012 Group Project Report

Authors
Juliano Calil
Alexander Silvester
Katharina Stelzl
Christopher Wissel-Tyson

Faculty Advisor
Professor James Frew

Client
The Innovation Center for U.S. Dairy

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JULIANO CALIL

ALEXANDER SILVESTER

KATHARINA STELZL

CHRISTOPHER WISSEL-TYSON

The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Masters of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

JAMES FREW, ADVISOR

March 2012

Abstract

Dairy farms are a major economic and cultural influence in many communities throughout the United States. Dairy products are part of a balanced diet and the fourth largest agricultural commodity in the United States. Climate change, however, is expected to negatively impact the industry in the future. Climatic events such as rising temperatures and atmospheric carbon dioxide concentrations will change the prices of dairy farms' inputs, including feed, fuel, and electricity. Higher temperatures additionally cause heat stress for dairy cows, leading to a reduction in milk yields. These impacts will pose additional burden on dairy farmers who operate on small profit margins. This project investigated how inputs critical to the dairy industry are effected by climate change, and the impacts this has on production costs. The project members created a tool to quantitatively assess these effects on dairy farms throughout the United States. Furthermore, the model shows how each impact contributes to the overall change in production costs. The results indicate that climate change will increase costs for the dairy industry, which may decrease farmers' profits. While climate change may negatively affect dairy farms, the model provides dairy farmers with a tool to calculate impacts specific to their farms, allowing them to understand the impacts of climate change and plan for the future.

Executive Summary

Introduction

The dairy industry has economic and cultural significance in the United States. Dairy is considered part of a balanced diet and the fourth largest agriculture commodity in America. In 2010, dairy farmers operated in all fifty states, producing over 192 billion pounds of milk. Operating on slim profit margins, dairy farmers are vulnerable to fluctuations in production costs and milk price. Climate change is expected to greatly impact dairy farmers. Crop yields will change due to variations in climate, affecting feed costs to farmers. In addition, climate change will affect energy and electricity costs. This project aims to understand the impacts of climate change on dairy farmers to help them plan for the future.

Objectives

The goal of the project was to identify the impacts of climate change on the dairy industry's critical inputs. To achieve this goal, the group members built a model that calculates the changes in production costs due to climate change. The model provides farmers with a tool to understand how climate change will affect their farm. The three main objectives of the study were as follows:

- Identify how climate change affects the critical inputs of the United States dairy industry
- Quantify the climate change impacts on production costs
- Model the change in total costs to farmers

Approach

The project members identified which inputs to analyze based on three evaluation criteria. The inputs needed to constitute a large fraction of a dairy farm's budget, be measurable with a reasonable level of certainty, and be directly affected by climate change. After conducting their analysis, the project members selected the following inputs to assess:

- Feed crops (corn, corn silage, alfalfa, and alfalfa silage)
- Energy (electricity and fuel)
- Heat stress

Feed comprises almost 50% of a dairy farmer's budget. Since corn and alfalfa make up a large portion of a dairy cow's feed, the project members specifically chose those feed inputs. Climate change is expected to impact those crops in different ways. While climate change is expected to decrease the yield of corn, causing corn prices to increase, alfalfa yields are expected to show a moderate improvement. As a result, the price of alfalfa was modeled as a slight drop in price. Additionally, climate change is expected to increase fuel and electricity costs. The final variable that the project members assessed was the effect of heat stress on dairy cows' milk yield. Heat stress causes cows to produce less milk with the same nutritional input, which effectively increases farmers' production costs. Furthermore, heat stress lowers the protein and fat content of milk.

The Model

The project members created a model to aggregate the individual changes in price of the selection variables. The model consists of four components, the change in feed costs, the change in energy costs, the change in other production costs, and the heat stress factor. The other production costs variable is a placeholder for future expansion of the model. The first three components of the model (feed, energy, and other) are weighted according to their contribution to the dairy farm's overall budget. The components are then summed to calculate the gross change in production costs. The gross change is adjusted by the heat stress factor. Since heat stress reduces milk yield per cow for the same amount of input, it serves as an indirect increase in total production costs.

Regions and Scenarios

For the purpose of this study, the U.S. was divided into five separate regions to improve the analysis of the impacts of climate change. First, the data on feed composition was divided in accordance to these regions. Second, climate change is expected to have regional effects on temperature. Third, dairy farm size and characteristics have geographic differences. Dairy farms in the West for example tend to be large farms with big herd sizes while dairy farms in the Midwest tend to be smaller. Farm size and location affects management practices and feed composition.

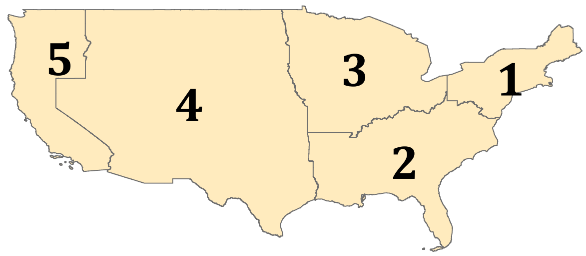

Figure 0-1: The five regions used in the study.

The literature revealed a wide range of predicted values for the variables included in the model. Generally, there was no consensus on the predicted changes. Therefore, the project members ran the model for three different scenarios:

- The low-response scenario used values predicting the least change in the model's inputs, thus producing a small change in production costs. These values were the lower bounds of the predicted ranges.
- The mid-level scenario used moderate responses to climate change. These values were taken from the middle of the range in literature values. This scenario was determined to be the most likely.
- The high-response scenario used values from the extreme, most negative, end of the estimated range of values to model a high-impact scenario.

By using this approach, the project members were able to estimate a range of expected changes to the production costs.

Results & Discussion

The results show that production costs will generally increase in all five regions of the U.S. The low response scenario showed a modest 1-4% increase in production costs. The medium response scenario caused larger increases in production costs, between 4 and 11%. The higher response scenario affected the farmers the most with an 12-18% increase in production costs. The model showed that a higher response to climate change led to greater increase in production costs. Therefore, the extent to which farmers will be affected by climate change depends upon the level of response of crop yields, energy prices, and heat stress to climate change.

Overall, the results indicate an increase in production costs for all regions no matter the scenario. Since dairy farmers have slim profit margins this increase is of concern for the industry. The results show that the main contributors across all regions to the cost increase are heat stress and feed. Changes in energy costs are negligible due to the fact that they make up a small percentage of the overall dairy farm budget. By analyzing these results, farmers can plan ahead for the changes to help prepare their businesses.

The increase in production costs varies by region. In addition, the factor that contributed the most to the cost increase depends on the region. Region 1, for example, does not experience any cost increases due to heat stress. Its greatest factor causing cost changes is feed. Region 2, on the other hand, has over 50% of its cost increases due to heat stress. Regional differences, therefore, are an important factor in the results.

In addition, some of the regions were large with diverse farm types and wide predicted temperature changes to climate change. The model, therefore, is more effective for a specific location and farm. A farmer could estimate the changes in costs for his individual farm by inputting his data into the model. Using exact input variables for feed composition, climate, and energy prices, the farmer would receive more precise changes in production costs than the results from scenarios with aggregate values for the large, diverse regions.

However, as mentioned earlier, there is still a high uncertainty in the numeric results. Since the majority of the literature values used in the model varies across a wide range, there needs to be more research to provide greater confidence in the numbers. In addition, the results use regional averages to characterize farms, which strongly impact the quality of the results due to a strong regional variability in parameters.

Recommendations & Conclusion

The results suggest that climate change will increase the production costs of dairy farmers. The model is an important first step toward designing a tool that helps farmers estimate the challenges they will face due to climate change. This understanding will enable farmers to plan their businesses for the future. In addition, the results provide the dairy industry with information about how they might be impacted by climate change. This study also highlights areas for further research.

Future improvements to the model include the following:

- Additional research concerning the response of feed crops to climate change and the related price changes
- Improved research on the predicted changes in energy costs
- The addition of adaptation and mitigation strategies to help farmers adapt to climate change and alleviate its adverse impacts.
- The inclusion of feed substitution effects that show how a farmer can reduce feed costs by switching to other feed sources.

Acknowledgements

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I. Project Background

A. Introduction to Dairy Farming

Dairy farming contributes both culturally and economically to the country's identity. In 2010, the United States had 53,127 dairy farmers who produced over 192 billion pounds of milk (NASS/USDA, 2011). Dairy farms are found in every state in the United States. Furthermore, dairies have been an integral part of many communities and regions for decades. The states of Wisconsin and Vermont, for example, are traditionally known as dairy states.

Not only do dairy farms have cultural importance, but they can also have a large economic impact, especially in certain states. In 2010, dairy products were the 4th largest agricultural commodity in the U.S., an estimated value of $31.4 billion (see figure 1 for the value for the top 10 states) (ERS, 2011b). On the state level, dairy was one of the five largest agricultural commodities in 28 states, and the largest in 11 states (Arizona, California, Idaho, Michigan, New Mexico, New York, Pennsylvania, Utah, Vermont, and Wisconsin) (ERS, 2011a). In some states, dairy comprised the majority of cash receipts for farms. For example, dairy accounted for 72.3% of agricultural commodities in Vermont (ERS, 2011b). In addition, the U.S. dairy industry employs over 176,000 workers with a payroll of over $2.4 billion (NASS/USDA, 2011d; BLS, 2011).

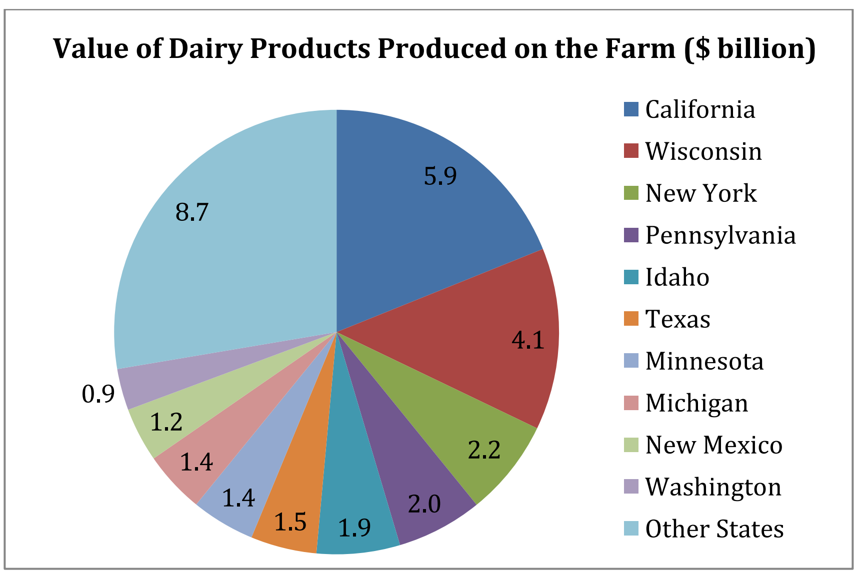

Figure 1: The top 10 state producers of milk in 2010. (ERS, 2011b)

The United States is a major player in the world's production of milk. In 2009, the world produced 1.29 trillion pounds of cow milk (ERS, 2011a). Since the 1970s, there has been a steady increase in the amount of milk produced except for the early 1990s. The amount of milk produced has increased 62% over this 40 year period (FAO, 2011a). The United States, the largest producer of cow milk, accounts for 15% of milk production worldwide, which is almost double the next largest producer, India at 8% (ERS, 2011a).[1] The top 10 countries produce 55% of the world's total. The U.S.'s, China's, India's, and Brazil's milk production have grown considerably over the past three decades while Europe's and New Zealand's milk production have remained steady over the past four decades (see figure 2).[2]

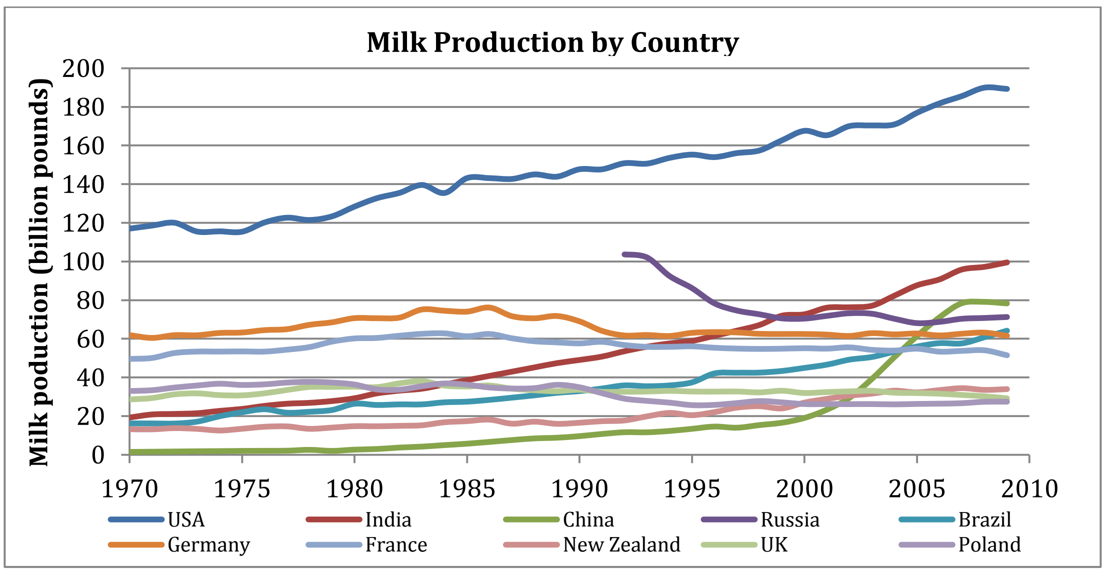

Figure 2: Milk production trends over the past four decades (FAO, 2011a).[3]

i. Major Trends in U.S. Dairy Farming

Over the past half-century, there have been major changes in dairy farming in the United States. While dairy farms numbered 648,000 in 1970, the amount of

[1] India also produces a substantial amount of milk from water buffalo. If water buffalo and cow milk is combined, India is the largest producer of milk in the world (FAOSTAT, 2010).

[2] The European Union operates under a quota system regulated by the Common Market Organization (CMO). European farmers may expand milk production when the quota system is expected to end in 2015 (BBC, 2008).

[3] Russia only appears in the early 1990s because it was previously combined with other Soviet republics and listed as the Soviet Union.

farms has dropped by over 90% to less than 53,127 today (MacDonald et al., 2007; NASS/USDA, 2011a). As the number of farms has declined, there has been a shift towards larger dairies, causing the number of cows on each farm to increase. In 1970, the average farm had 19 cows, while it houses over 170 cows today (MacDonald et al., 2007; NASS/USDA, 2011a).[4] In addition to a change in farm size, there have been geographic shifts in the location of dairy farms. Large dairy farms, which were more traditional in California, are starting to expand in the Midwest (Cross, 2006). Changes in farm size may be linked to geographic changes in production (MacDonald et al., 2007).

In addition to changes in farm structure and geography, the total number of cows has fallen. Today, there are almost 9 million lactating cows, around 3 million fewer than the 12 million lactating cows in 1970 (MacDonald et al., 2007). [5] However, milk production in the United States has steadily increased (see figure 2). This is possible due to the fact that milk yields have dramatically improved. Milk yields per cow went from under 10,000 pounds per year to over 20,000 pounds over the past 40 years (MacDonald et al., 2007; NASS/USDA, 2011b).

ii. Dairy Farms and Herd Size

The United States Department of Agriculture (USDA) identifies the number of dairy operations that are licensed to sell milk. These farms are a subset of the total number of dairy farms.[6] Since this report focuses on the effects of climate change to commercial farmers, the facts and statistics presented in the report will reflect the number of farms licensed to sell milk unless otherwise noted.

As stated earlier, the total number of dairy operations is decreasing. The number of licensed farms has also seen a dramatic fall. Over the past two decades, there has been a 57% drop in the number of licensed farms (see figure 3). Average herd size, on the other hand, rose 124% in 18 years. While there were on average 77 cows on a farm in 1993, it was estimated that there were 172 cows

[4] The number of cows includes lactating cows and dry cows, but excludes heifers not yet fresh.
[5] The number of cows refers to the number of milk cows on a farm. Milk cows are cows that can produce milk, which include cows that are milking and dry cows (cows that are preparing to give birth). In addition, dairy farms may have bulls, calves, and heifers (cows that have not started to produce milk), which are not included in the cow numbers presented throughout this report.
[6] In 2010, 9,373 of the 62,500 dairy farms were not licensed to sell milk in the United States (NASS/USDA, 2011c).

on a farm in 2010 (see figure 3). The average size of the herd is increasing due to changes in dairy farm structure as the industry moves toward fewer, larger dairies.

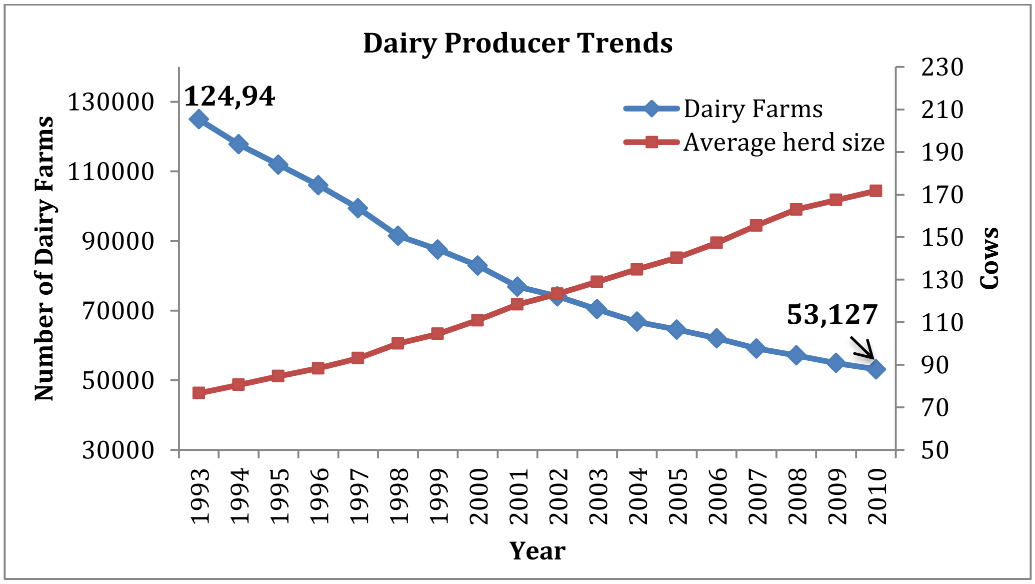

Figure 3: The number of dairy farms and average herd size over the past 18 years. (NASS/USDA, 2011c).

iii. Cow Population

While the cow population in the United States has decreased by almost 3 million lactating cows since the 1970s, the past decade has not seen a similar trend. The number of lactating cows has fluctuated between 9.0 and 9.3 million cows over the last 10 years (see figure 4). While one might assume that milk production would rise and fall in accordance with cow populations, milk production has shown a steady increase. Over the past 10 years, milk production has increased 16% (NASS/USDA, 2011c).

The rise in milk yield per cow has allowed for this trend in milk production. From 2001 to 2010, average milk yield increased from 18,162 to 21,149 pounds per cow, or 16%. This rise in milk yield has allowed milk production to rise even though cow populations have decreased. For example, total milk production rose from 189 billion pounds in 2009 to 192 billion pounds in 2010 as cow populations dropped by 300,000. The rise in milk yields is due to a wide range of factors including genetic improvements (Shook, 2006), improved nutrition (Eastridge, 2006), optimal heat abatement (St-Pierre et al., 2003), increased number of milkings (Khanal et al., 2010), and barn remodels (Cook et al., 2008).

Due to these factors, the United States is one of the leaders in the world for milk yield per cow (FAO, 2011a).

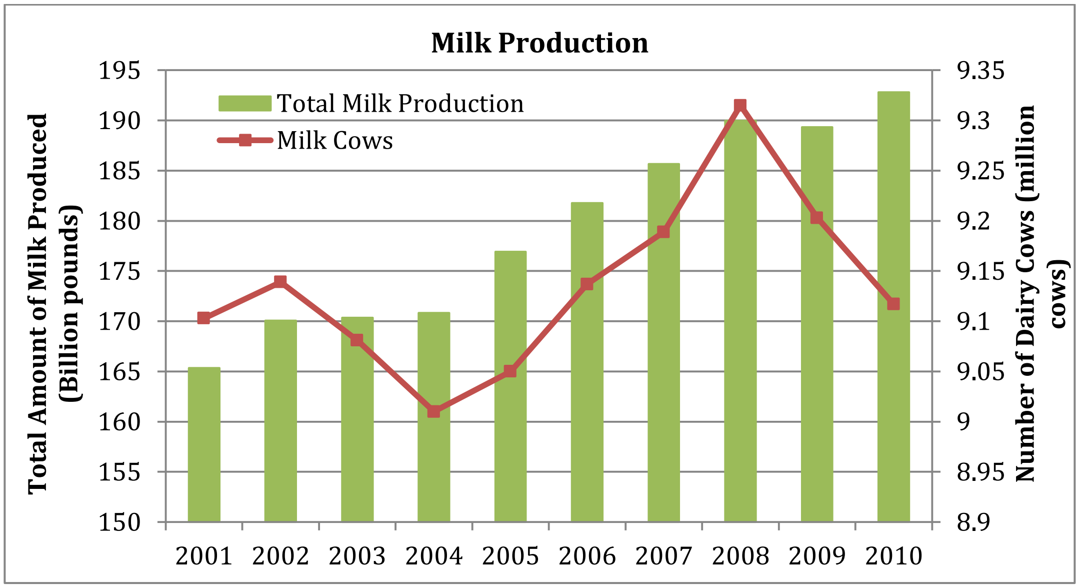

Figure 4: Trend in milk production and cow populations over the past decade (NASS/USDA, 2011c).

Organic milk makes up a small percentage of the total amount of milk produced each year. In 2005, the number of USDA organic certified cows made up 0.96% of all lactating cows in the United States. This figure has since increased to 2.7% in 2008 (ERS, 2012). The percentage of organic milk in the total milk production is expected to be lower than the percentage of organic cows in the total herd, because organic cows generally have lower yields than non-organic cows. Since they have lower yields, they contribute less to the total milk supply.

iv. Dairy Farm Structure

There is a huge variety in the size of dairy farms ranging from under 30 cows to over 15,000. Small and large farms differ in several characteristics (MacDonald et al., 2007). Small farms generally do not hire labor because farms are run by the owners and their families. Small farms tend to grow a larger portion of their feed and raise their calves on site. While large farms are also generally family-owned, they tend to purchase a larger portion of feed and rely on hired labor.

The smallest farms have fewer than 30 cows. The owners of these farms generally work on other business activities in addition to dairy farming. Dairy farms begin to specialize in dairying with 30-200 cows. The number of small farms (fewer than 50 cows) is decreasing. The number of farms with less than 50 cows decreased by 12% from 2006 to 2010 (See Table 1). While small farms make up 50% of the total number of dairy farms, they produce less than 5% of the milk produced in the U.S. In addition to the smallest farms, operations with 50-99 cows and 100-499 cows have decreased by 30% and 33% respectively (NASS/USDA, 2011a).

Table 1: Changes in Farm Size & Production (NASS/USDA, 2011a)

	Number of Farms[7]		**Percent of**	
	Total Number in 2010	Percent Change from 2006	Total Farms in 2010	2010 Milk Production
1-49 Cows	31000	-12%	49.6 %	4.6 %
50-99 Cows	15500	-30%	24.8 %	10.4 %
100-499 Cows	12600	-33%	20.1 %	24 %
500-999 Cows	1720	12%	2.8 %	13 %
1000+ Cows	1680	16%	2.7 %	48 %
Total	**62,500**		**100 %**	**100 %**

Meanwhile, the number of large farms is increasing. The number of farms with 500-999 cows increased 12% while the number of farms with over 1000 cows increased by 16% (NASS/USDA, 2011a). Large farms (over 500 cows) make up only 5% of U.S. dairy farms, but they produce 61% of the milk (see table 1). Therefore, large farms have a substantial impact on the amount of milk produced each year.

The restructuring of the industry is due to economies of scale. A survey of dairy farms found that large dairy farms generally generate profits, while small dairy farms are more likely to generate a loss (McDonald et al., 2007). The difference in profit between the farm sizes is due to economies of scale where large farms can spread their costs over a larger amount of milk. The Economic Research Service conducts an annual survey of dairy farmers that shows this effect (see table 2). Large dairy farms are able to drastically reduce their costs per unit of milk compared to smaller dairies. Since farmers generally lose money as a small farm and gain more the larger their size, there is a strong incentive to be a larger farm.

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[7] The number of farms refers to all dairy operations including those that are not licensed to sell milk. If only licensed operations were included, the number of small farms would be a smaller percentage of the total number of dairy farms.

Table 2: Production Returns and Costs for 2010 (dollar per cwt sold)[8] (ERS, 2011c)

	Fewer than 50 cows	50-99 cows	100-199 cows	200-499 cows	500-999 cows	1,000 cows or more
Gross value of production	19.32	19.02	18.54	18.77	17.99	18.01
Costs						
Total operating costs	15.47	15.96	14.81	14.72	15.09	13.58
Total allocated overhead	20.39	14.57	10.87	7.81	5.96	4.62
Total costs listed	35.86	30.53	25.68	22.53	21.05	18.20
Value of production less total costs[9]	-16.54	-11.51	-7.14	-3.76	-3.06	-0.19

v. Distribution and Variability of Dairy Farms

While dairies exist in every state of the United States, there are regional trends. Traditional dairy regions, such as New England and the Midwest, generally have smaller dairies. The west coast and the plains states are known for larger dairy farms. Even though some areas are known for large or small dairies, there is large variability within each region. In addition, larger farms are growing everywhere, including traditional dairy states (MacDonald et al., 2007). There is also great variability in milk yields between the different regions and states. New Mexico, for example, has the highest milk yield (the amount of milk produced per cow per year) at 24,551 pounds while Hawaii's milk yield is 13,316 pounds (NASS/USDA, 2011c).

Dairy Regions

For the purposes of this study, the country was divided into the 5 regions (see figure 5) as defined in the life cycle assessment conducted on a gallon of fluid milk by the University of Arkansas and Michigan Technological University (UA & MTU, 2010). Region 1 includes most of the New England and Mid-Atlantic states.

[8] CWT is the abbreviated form of centum weight, equating to 100 lbs of milk. This is a dairy farmer's unit of measure.

[9] The value of production less total costs is not the same as a dairy farmer's profit. The Economic Research Service (ERS) includes the opportunity cost of the farmer as part of their costs. Therefore, a farmer generates a higher income than the value of production less total costs indicates.

Region 2 is made up primarily of the southern states. Region 3 is comprised of a portion of the Midwestern states while region 4 includes the rest of the Midwestern states, the plain states, and part of the American southwest. Region 5 includes the states along the western coast of the United States, Alaska and Hawaii.

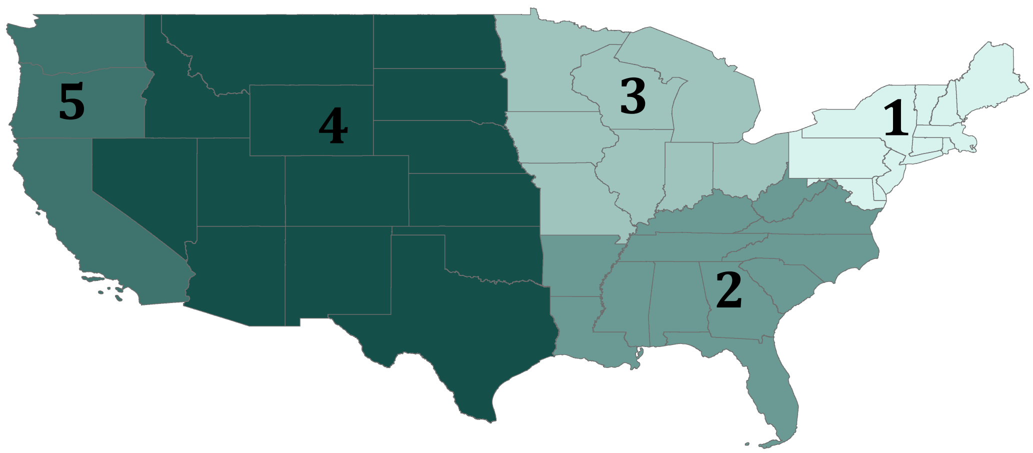

Figure 5: The five study regions used for the U.S. (UA & MTU, 2010).

Region 1 is comprised mainly of traditional dairy states. New York, Pennsylvania, and Vermont are some of the top producing states in the region. Many of the U.S.'s dairy farms are located in region 1, around 29% of the country's total, but they tend to be smaller farms, with an average herd size of 95 cows per farm (see table 3). In addition, these farms tend to grow a larger proportion of their feed. Region 2 is not considered a high dairy-producing region. There are no states in the top 15 and combined they only produce 5% of all milk produced in the U.S. Florida is the highest producing state in region 2. The region has a smaller number of farms with a slightly larger herd size than region 1 at 157 cows per farm. In addition, they have a very low milk yield per cow, which is over 4,000 pounds per cow less than the national average.

Region 3 contains many traditional dairy states. These states are some of the highest producing states in the country including Wisconsin, Minnesota, and Michigan. This region contains 54% of the total number of U.S. dairy farms. While they account for the majority of farms, they only produce 31% of the milk due to small herd size and a milk yield that is slightly below the national average. Farms in this region purchase a larger portion of their feed.

Table 3: Dairy farm statistics for the different regions (NASS/USDA, 2011b)

Region	No. of States	No. of Farms	Milk Production (billion pounds)	Average Herd Size	Milk Per Cow (pounds per yr)
1	11	15,175	28.7	95	19,991
2	12	3,480	9.3	157	17,046
3	8	28,670	59.9	102	20,377
4	14	3,355	46.2	618	22,274
5	5	2,447	48.7	869	22,920
Total	50	53,127	192.82	172	21,149

Regions 4 and 5 are dominated by large dairies that mainly purchase their feed. Even though region 4 only accounts for 6% of the farms, they produce 24% of the milk. This region contains many top 15 dairy producing states including Idaho, New Mexico, Arizona, and Texas. They have large herds with high milk yields. Region 5 contains California, which produces 55% more milk than the next largest state in the U.S. Like region 4, region 5 has a small percentage of the total farms, but produces 25% of the milk. These regions also contain large herds with an average herd size that is at least 3.5 times larger than the national average.

vi. Farm Price and Farm Profitability

Two major impacts on the profitability of dairy farms are the price of milk received by farmers and the cost of feed prices. Over the past five years, the price of milk has dipped below $12 per hundredweight and risen as high as almost $22 per hundredweight (see figure 6). The volatility and variability of milk price can cause economic problems for dairy farmers. In 2008, when milk farm prices decreased dramatically, farmers were put under extreme financial stress (Shields 2009). The rise in feed prices over the same period made the situation even worse.

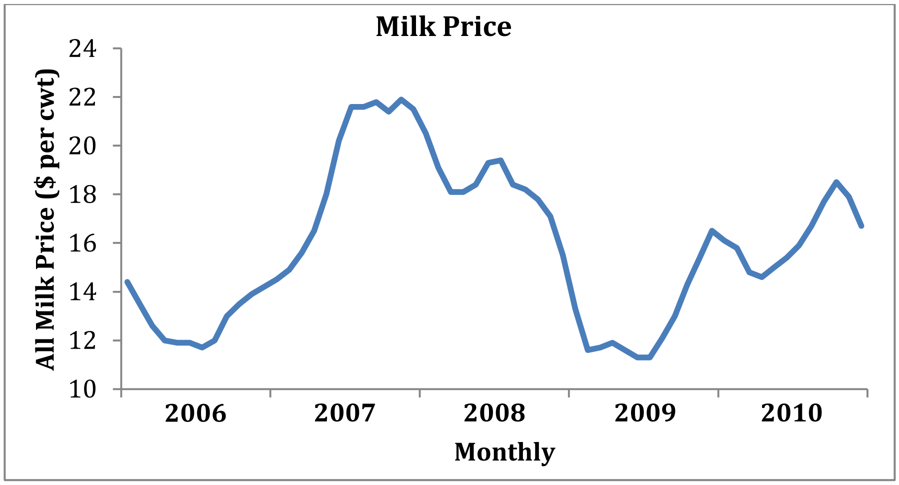

Figure 6: The price of milk over the past five years (NASS/USDA 2011c).

The pricing of milk is complex due to the production, assembly and distribution of milk (Manchester & Blayney, 2001). The federal government has developed programs to help stabilize the price of milk and guarantee the purchase of dairy products at a specific price. Other programs include import restrictions, export subsidies, and domestic and international food aid programs. Since milk is produced every day and is perishable, milk supply in the short term cannot match dairy demand (Machester & Blayney, 2001). The recent volatility in milk price is attributed to a variety of factors including an increased dependence on exports (Shields, 2009). Furthermore, it has been hypothesized that the rise and fall of farmer milk price is not correlated with the rise and fall of retail milk price (Shields, 2009). These issues indicate that an increase in production costs might not affect the farm price of milk.

B. Climate Change and Agriculture

i. Agriculture in the 21st Century

Over the past 50 years, global demand for agriculture products and water has risen dramatically. Global agriculture demand has grown almost threefold while the overall cultivated area has grown by only 12% (FAO, 2011b). Irrigated areas are responsible for almost 50% of the food production growth, and its total area has doubled during the same period (FAO, 2011b). Today, crop production uses 11% of the world's land surface and a staggering 70% of all the fresh water available on land (FAO, 2011b).

During the next 50 years, the global population is expected to grow to anywhere from 9 to 10 billion people, a 30% increase from today (FAO, 2011b). Global per capita GDP is expected to grow 140% causing global consumption to grow by a similar amount (FAO, 2011b).

Meeting such a rapid increase in demand will not be easy and both global and local challenges will have to be overtaken. At a global scale, how will demand be met? What will be likely environmental impacts of meeting this demand? What kinds of water management strategies will be required so the water needed to supply this demand is available? How much can global yields improve during the next 50 years? These and other questions will need to be answered.

One of the toughest challenges producers will face to meet global food demand is climate change. It will be hard enough to meet the rapidly growing demand on a stable climate. If farmers could rely on the past as a safe predictor of the future, they would be able to plan their crops accordingly and safely predict future production within acceptable error margins. Unfortunately, under a dynamic climate, things are not so simple. Changes in climate will result in changes in average and extreme temperatures, changes in precipitation leading to more droughts in some areas and more intense rains in others.

In regions like the Pacific Northwest of the United States, scientific evidence leads to a future where more precipitation is likely to fall as rain instead of snow, fundamentally altering the hydrological cycle of the region. According to Stewart et al. (2004), the reduction of mountain snow accumulation leading to a reduction of the snowmelt driven water supply is one of the primary consequences of a warmer climate. Reduced snow precipitation is likely to affect the water supply for California, one of the most important regions for dairy farms.

Finally, the agriculture sector has a large environmental impact. Even though agriculture is responsible for almost 14% of global Greenhouse Gas (GHG) emissions (figure 7), it is not in the scope of this study (Baumert et al., 2005). The analysis instead focuses on the possible impacts of climate change on the critical inputs of the dairy industry in the United States during the next 40 years.

ii. A Quick Overview of Global and Domestic CO_2 Equivalent Emissions

While the study does not focus on GHG emissions, it is beneficial to briefly analyze the current level of GHG emissions. The following is a brief summary of the most recent global and domestic CO_2 equivalent emissions.

The world's population produces about 44,153 metric tons of CO_2 equivalents yearly (Baumert et al., 2005). These are produced by 9 major sectors: electricity and heat (24.9%), industry (14.7%), transportation (14.3%), agriculture (13.8%), other fuel combustion (8.6%), industrial processes (4.3%), fugitive emissions (4.0%), waste (3.2%), and land use change (2.2%) (figure 7) (Baumert et al., 2005).

Despite the worldwide economic slowdown, GHG emissions increased by alarming volumes in 2010. According to recent estimates from the International Energy Agency, a record 30.6 gigatonnes of CO_2 were released into the atmosphere in 2010 (EIA, 2011). Due to the recent economic troubles in the U.S., GHG emissions during the years 2007 and 2008 were lower than 2006 but 2009 emissions were still 7.3% higher than 1990 levels (EIA, 2011). According to the World Resources Institute, the agriculture sector was responsible for 13.8% of global GHG emissions in 2005, very close to the global industrial emissions for that same year of 14.7% (EIA, 2011).

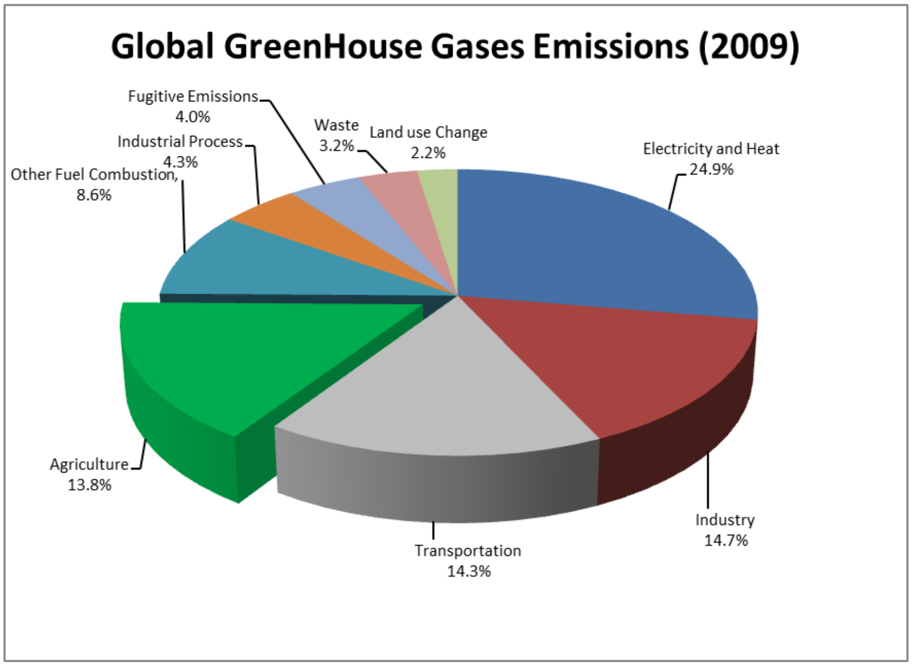

Figure 7: Global GHGs Emissions by sector (WRI, 2010).

According to the most recent U.S. GHG inventory from the EPA, the total U.S. GHG emissions in 2009 were about 6.6 gigatonnes of CO_2 equivalent (EPA, 2011). The agriculture sector was responsible for 419 megatonnes, 6.3% of total domestic CO_2 emissions in 2009 (EPA, 2011).

Table 4: Total U.S. emissions (Tg or million metric tons of CO_2 equivalent) (EPA, 2011)

Chapter/IPCC Sector	1990	2000	2005	2006	2007	2008	2009
Energy	5,287.8	6,168.0	6,282.8	6,210.2	6,290.7	6,116.6	5,751.1
Industrial Processes	315.8	348.8	334.1	339.4	350.9	331.7	282.9
Solvent and Other Product Use	4.4	4.9	4.4	4.4	4.4	4.4	4.4
Agriculture	383.6	410.6	418.8	418.8	425.8	426.3	419.3
Land Use, Land-Use Change, and Forestry (Emissions)	15.0	36.3	28.6	49.8	47.5	33.2	25.0
Waste	175.2	143.9	144.9	144.4	144.1	149.0	150.5
Total Emissions	**6,181.8**	**7,112.7**	**7,213.5**	**7,166.9**	**7,263.4**	**7,061.1**	**6,633.2**
Net CO_2 Flux from Land Use, Land-Use Change, and Forestry (Sinks)[a]	(861.5)	(576.6)	(1,056.5)	(1,064.3)	(1,060.9)	(1,040.5)	(1,015.1)
Net Emissions (Sources and Sinks)	**5,320.3**	**6,536.1**	**6,157.1**	**6,102.6**	**6,202.5**	**6,020.7**	**5,618.2**

[a] The net CO_2 flux total includes both emissions and sequestration, and constitutes a sink in the United States. Sinks are only included in net emissions total.

Note: Totals may not sum due to independent rounding. Parentheses indicate negative values or sequestration.

iii. Global Climate Change

Recent studies demonstrate that the effects of global climate change have already been observed in several regions of the world (IPCC, 2007). Such evidence includes an increase in air and water temperatures, sea level rise, reduced snow, glacier and artic ice cover, reduced number of frosty days, and changes in precipitation regimes (IPCC, 2007).

Climate Models

Scientists have been using conceptual models, simplified versions of complex systems or processes, as research and communication tools. Scientific models are useful tools that provide knowledge about systems that are otherwise impossible to represent in their totality.

The Intergovernmental Panel on Climate Change (IPCC) relies on sophisticated climate models developed to provide insight into possible future scenarios. Complex climate models are based on general circulation models (GCMs) and are coupled with ocean-atmospheric models to simulate Earth's climate system. One of the main objectives of global climate models is to investigate the sensitivity of the climate system to various forcing factors including solar radiation, anthropogenic GHGs, aerosols emission, etc. GCMs use mathematical models and powerful computers to advance knowledge of how the atmosphere, the oceans and climate function. The IPCC Assessment Reports use multiple global climate models and publish their results alongside with multiple model averages.

Since projections of climate change depend heavily on human activity, climate models rely on various scenarios that try to describe possible futures. Several factors, including demographic development, socio-economic development and advances in technology, affect the levels of GHG emissions and their atmospheric concentrations. Additionally, mitigation actions may also impact how climate will change.

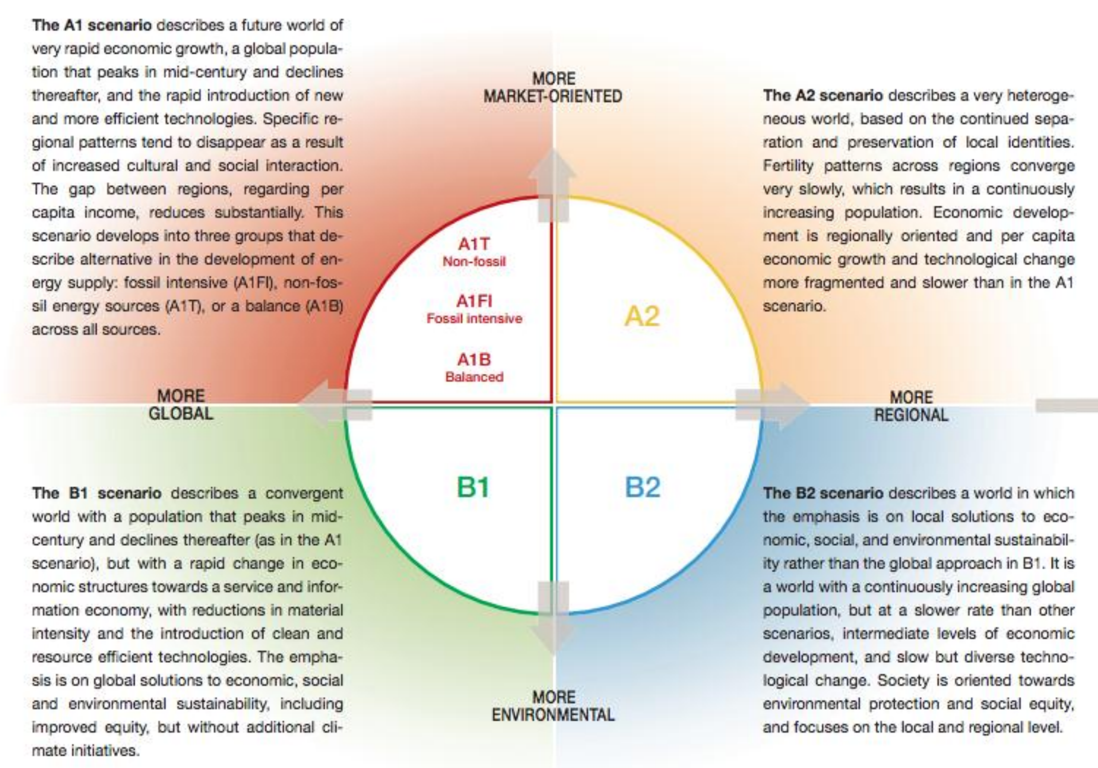

Figure 8: A description of the four emission scenarios (UNEP, 2005).

The last two IPCC reports, the IPCC Third Assessment Report (TAR), published in 2001, and the IPCC Fourth Assessment Report (AR4), published in 2007, rely on four scenario families that were defined in the Special Report on Emissions Scenarios (SRES), published in 2000. The four SRES scenario families are described in figure 8. Each scenario predicts a different level of warming. Figure 9 displays estimated temperature increases for each scenario family.

	Global mean warming (°C)				Measures of agreement (M × 100, *mae* × 100)			
	2011–2030	2046–2065	2080–2099	2180–2199	2011–2030	2046–2065	2080–2099	2180–2199
A2	0.64	1.65	3.13		83, *8*	91, *4*	93, *3*	
A1B	0.69	1.75	2.65	3.36	88, *5*	94, *4*	100, *0*	90, *5*
B1	0.66	1.29	1.79	2.10	86, *6*	89, *4*	92, *3*	86, *6*
Commit[a]	0.37	0.47	0.56		74, *11*	66, *13*	68, *13*	

Figure 9: Temperature increases under different climate scenarios (IPCC, 2007).

Temperature Anomalies

The last four decades have shown a substantial increase in global average temperatures. Researchers have collected thousands of measurements from multiple sources including weather stations and satellite data. The IPCC working group I, which is responsible for reporting "The Physical Science Basis" of Climate Change, has compiled multiple independent studies from several renowned research groups. Figure 10 shows the observed temperature variations from 1880 to 2000. It is worth mentioning that 2011 was the 11th warmest year ever recorded.

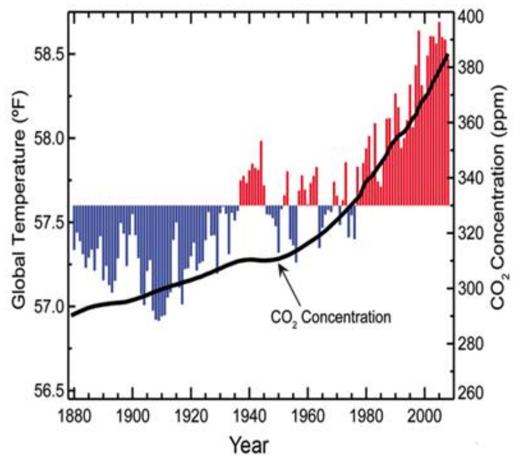

Figure 10: Annual average temperatures for the past 130 years (IPCC, 2007).

Projected Temperature Changes Across the U.S.

Temperatures are not expected to increase evenly across the United States under the different climate change scenarios. The western most states and part of the Deep South are projected to have smaller increases in temperature than the plains states, the Midwest and New England (see figure 11). Under the A2 scenario, temperatures are projected to increase between 2 to 4 degrees Celsius by 2050 (IPCC, 2007).

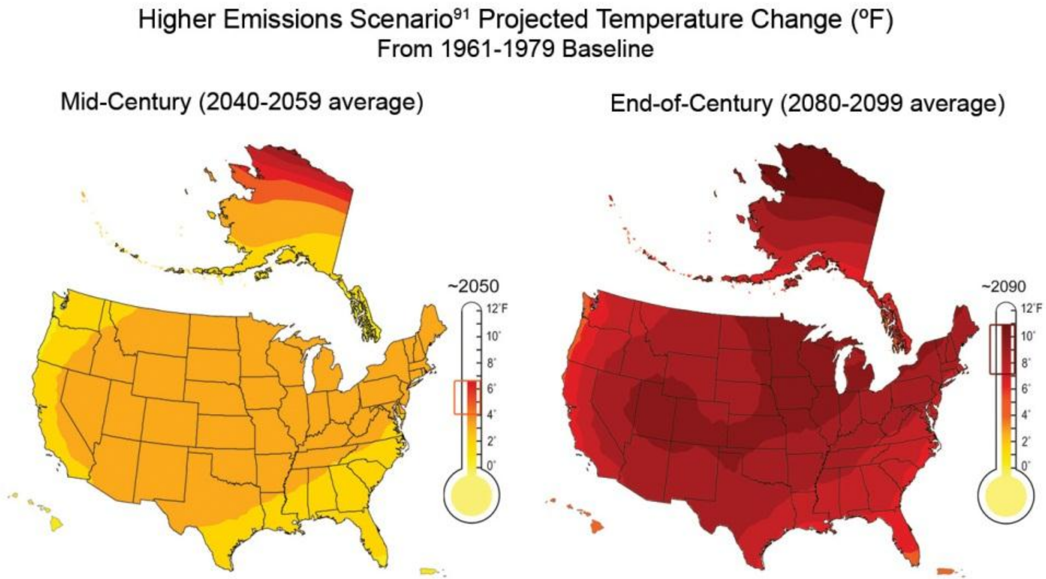

Figure 11: Temperature changes under the A2 scenario (IPCC, 2007)

Precipitation Anomalies

According to the Fourth Assessment Report of the IPCC, the frequency of heavy precipitation events is very likely to increase (>90% probability) in the future. At the same time, the areas affected by droughts are likely to increase as well (>66% probability) (IPCC, 2007). The intensity and duration of droughts are also expected to increase. In fact, since the 1970's, the area affected by longer and more intense droughts has risen, particularly in the tropical and subtropical regions (IPCC, 2007). Droughts have also been linked to changes in snowfall regimes and variations in sea surface temperature (IPCC, 2007).

During the last century, parts of the Americas, northern Europe as well as central and northern Asia have experienced significant increases in precipitation. Conversely, other parts of the world have experienced drying, including the Sahel, the Mediterranean, southern Africa and parts of southern Asia. It is important to note that long-term trends were not observed in other large regions assessed by the IPCC SRES scenarios.

In the U.S., future precipitation changes will vary by season and location (see figure 12). Some parts of the U.S. are expected to receive less rainfall while other regions are expected to receive more. In the summer, almost the whole U.S will experience less precipitation while many areas of the U.S. will receive more precipitation in the fall.

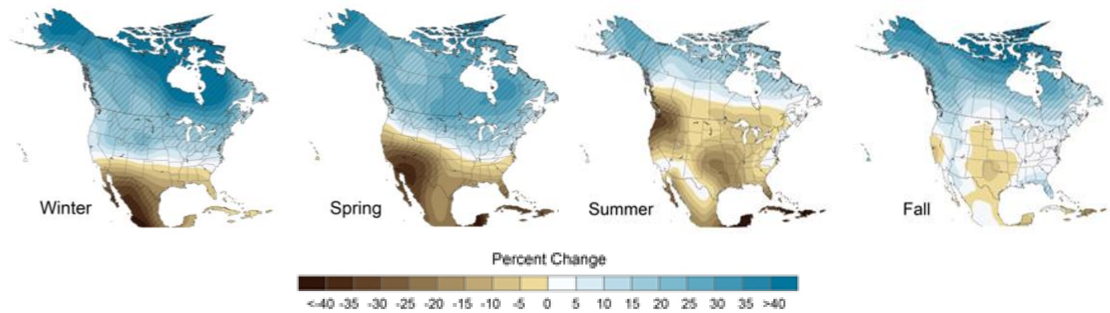

Figure 12: Precipitation changes due to climate change (IPCC, 2007).

iv. An already Changing Climate

Recent scientific studies suggest that certain regions in the U.S. are already experiencing the effects of climate change. Regions like California are experiencing a larger number of warm days and nights and longer droughts (IPCC 2007). Recent studies suggest that the Pacific Northwest of the United States has already experienced a temperature increase of 1°C to 2°C over the last 60 years, leading to an increase of precipitation as rain instead of snow and to an earlier snowmelt, altering the region's water cycle (Wolin & Daly, 2004).

Pacific Northwest

During the last 60 years, temperatures around the Pacific Northwest have already increased between 1°C and 2°C. The region's snow cover has also declined. While climate change will continue to affect snowfall patterns across the Pacific Northwest region, certain areas and types of snow are more likely to be impacted than others. A 2006 study from scientists Nolin and Daly, from Oregon State University, suggests that warm areas, at lower elevations, are at higher risk of experiencing warmer winters than colder areas at high elevations. Relying on historical records of temperature, precipitation and wind patterns, Wolin and Daly's model proposes that low elevation areas of the Pacific Northwest (including the northeast region of Mount Hood, Oregon) are likely to experience approximately one warm winter (with average temperatures above 0°C) every three years, leading to earlier snowmelts and lower availability of water from snowmelt later in the year (Wolin and Daly, 2004).

California

Perhaps more relevant to the dairy industry is California. According to detailed records of California's Department of Water Resources (DWR), climate change can have important consequences for the state's water resources. DWR has detailed records that date back to the early 1900's, and the data show that water volumes from April to July have declined while January to March flows have increased (Climate Energy Commission, 2003).

v. The Impacts of Climate Change on Crops

Climate change in the U.S. is expected to have a significant impact on crop yields in certain regions. There are many aspects of climate change that could affect crop yield. The scope of this report only looks at the effects of increased temperature and elevated CO_2 levels in the atmosphere on crops. Climate change will have other effects on crops, but they are outside the scope of this analysis.

One effect is the increased impact of weeds and pests on crops. While elevated CO_2 levels will increase the growth of many crops, the positive growth effect is expected to be even greater on weeds. The temperature increase will also cause the spread of invasive weed species into new areas where they previously could not survive (Hatfield et al., 2008).

In addition, longer growing seasons allow some insects to produce more than one generation of offspring per season, resulting in a greater number of insects and pests. Since plants grown under higher CO_2 concentrations tend to be less nutritious, the insects must eat more plant material to meet their nutrient requirements, thereby creating even greater harm. (Hatfield et al., 2008)

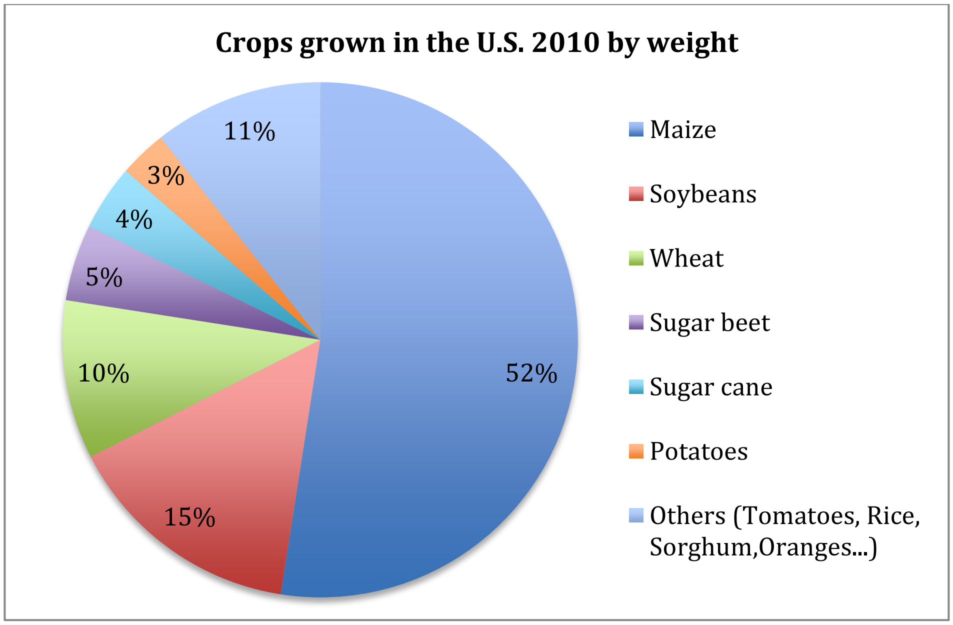

Figure 13: Crops grown in the U.S. in 2010 by weight produced (FAOSTAT, 2012).

Due to the increased presence of pests, warmer regions are sprayed with more pesticide than cooler regions. Sweet corn farmers in Florida spray their fields between 15 to 32 times a year to fight pests such as corn borer and corn earworm, while their colleagues in New York average zero to five applications in the same time span. In addition, higher temperatures are known to reduce the effectiveness of certain classes of pesticides such as pyrethroids and spinosad (Hatfield et al., 2008).

Figure 14: The left photo shows weeds in a plot grown at a carbon dioxide (CO_2) concentration of about 380 parts per million (ppm), which approximates the current level. The right photo shows a plot in which the CO_2 level has been raised to about 680ppm. Both plots were equally treated with herbicide (Karl et al., 2009).[10]

Problems with predicting the impact of climate change on crops

One of the obstacles in drawing conclusions about the effect of climate change on crop yields is the rapid technological development of the agriculture industry. Technological improvements as well as a modernization in agricultural practices have increased crop yields in a manner that may offset the negative effects of climate change, resulting in no measurable loss in agriculture productivity.

However, there are numerous manipulative studies that try to quantify the impact of changes in temperature and atmospheric CO_2 concentration on crops. Unfortunately, most of these experiments have been conducted under different circumstances. Some of the studies changed only the temperature while others only increased CO_2. Additionally, some studies increased solar radiation on

[10] The photograph is taken from (Karl et al., 2009) and cited there as (Wolfe et al., 2008), but could not be found in the original paper.

plants. These studies were either conducted in greenhouses and field-studies, and the crop varieties were different for the different studies. These differences make it difficult to assess and compare the results from different researchers to identify a trend or direction (Hatfield et al., 2008).

vi. Corn

Corn *(Zea mays)* is a cereal plant very common in North America. It is a C_4-plant that was domesticated by indigenous people in Mesoamerica in prehistoric times. Corn accounts for about 34% of the world's total grain production. It is mainly used as animal feed, corn ethanol, and high-fructose corn syrup for the food industry. In Latin America and Africa, it is an important part of people's diet.

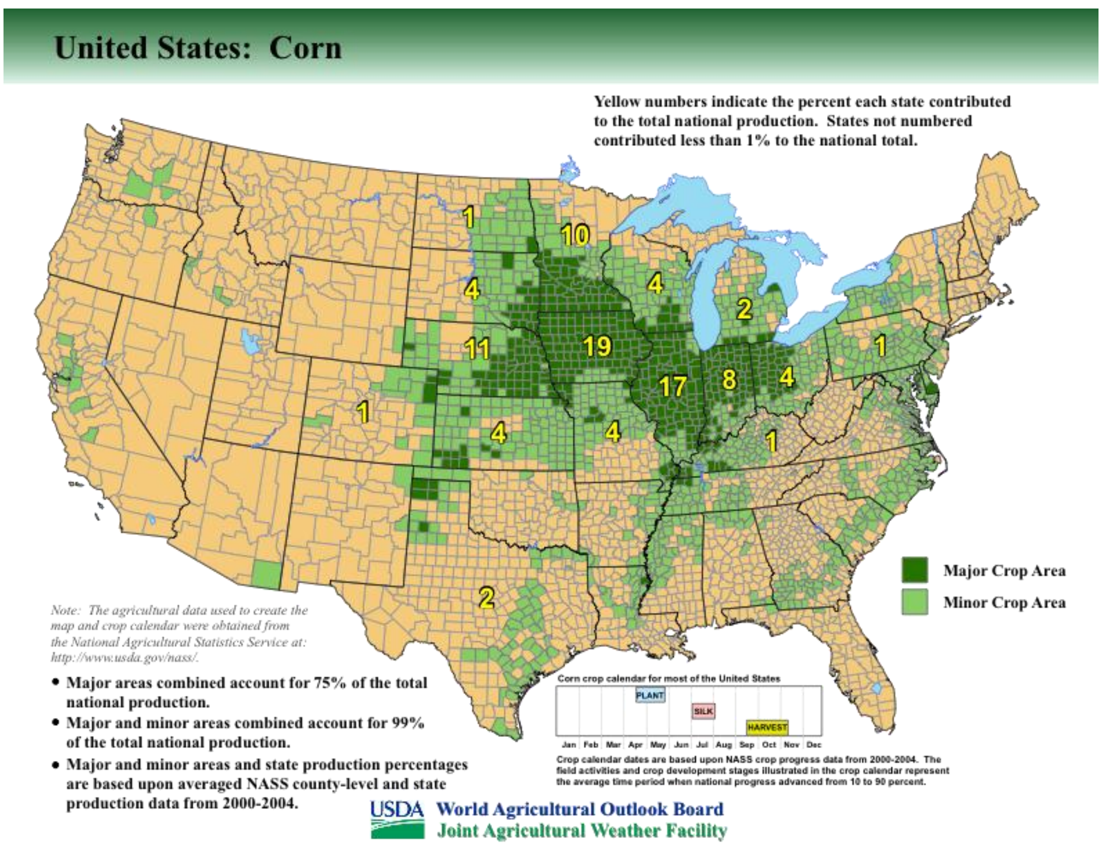

Figure 15: Corn production in the U.S. by region between 2000 and 2004 (USDA Maps 2012).

Corn is grown in most parts of the world, but the United States is by far the largest corn producer with an annual production of 331 million metric tons in 2010, which accounts for 39% of the world's corn production. Figure 15 shows that the vast majority of corn production in the United States is located in the

Midwest. More than 50% of the corn produced in the U.S. is grown in only four states: Iowa, Illinois, Nebraska and Minnesota. Other major corn-producing states are Indiana, Wisconsin, South Dakota, Michigan, Missouri, Kansas, Ohio, and Kentucky (U.S. Grains, 2012).

Figure 16 shows that corn production, while not monotonous, has overall been rising over the last decade. The production increased by 23% in ten years.

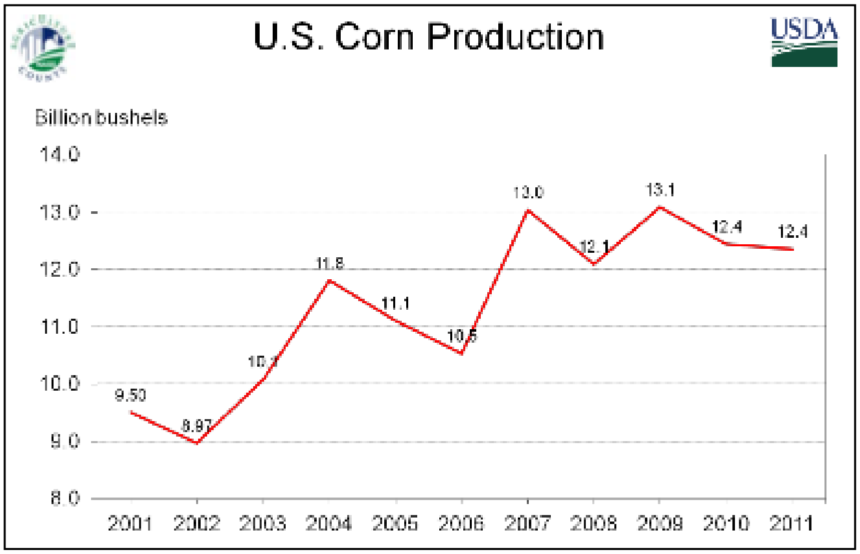

Figure 16: U.S. Corn Production between 2001 and 2011 (USDA Statistics, 2012).

Dairy cows are fed corn either as grain or corn silage. Silage is produced by chopping the whole corn plant and storing it under conditions that favor an anaerobic fermentation process to delay spoiling. Silage has a high water content of 60% to 80% (Crop Glossary, 2012).

Climate Change effects on Corn

Elevated Temperature

Several studies have been conducted to investigate the impact of increased temperature on corn yield. However, the results of these studies are hard to compare since they were conducted in different parts of the United States and world at different temperature increases and varying observation times. Some of the studies were performed in laboratories or green houses (Badu-Apraku et al., 1983); others were analyses of data collected in the field (Lobell & Field, 2007; Muchow et al., 1990).

Elevated temperatures cause the maize life cycle to shorten, which reduces growth time and thus corn yield (Badu-Apraku et al., 1983; Muchow et al., 1990).

Badu-Apraku and colleagues studied short season maize that was grown outdoors until 18 days post-silking. It was then transferred into a controlled environment, growth-cabinets. There the plants were exposed to different temperature regimes to research the effect of temperature on grain-filling as well as total biomass of the plant. The experiment showed that the growth season under higher temperatures was concluded faster than at cooler temperatures and that the shorter growth period resulted in a decrease in biomass production during grain filling, thus reducing crop yield (Badu-Apraku et al., 1983).

Muchow et al. (1990) found the highest observed and simulated grain yield in relatively cool temperatures (growing season mean between 18.0 and 19.8°C in Grand Junction, CO), because growth life cycles were longer compared to warmer sites. These studies result in an estimate of 4% yield decrease at a temperature rise of 1.2°C in the Midwest, assuming irrigation or water-sufficient management. However, the yield decrease in this study might have been underestimated, since the researchers did not take into consideration what effects temperature change could have on assimilation and respiration. In addition, they also did not account for failure in grain set with rising temperature.

Lobell and Field analyzed global maize production between 1961 and 2002 and correlated it with the average temperature in any given year. They found that yield decreased by 8.3% for every 1°C rise in temperature (Lobell & Field, 2007).

Given the huge disagreement in literature estimates and lack of real manipulative temperature experiments on maize the estimates in
should only be considered "possible to likely" (Hatfield et al., 2008).

Table 5: Response in corn yield to temperature and CO_2 increase per 1°C and 100ppm CO_2 as summary of the literature cited in Hatfield et al. (2008).

	Temperature (1°C)	**CO_2 (100 ppm)**
	% change	
Corn	- 3.33	+ 1.67

Elevated CO_2 Concentrations

It has been shown in multiple studies that elevated CO_2 concentrations in the atmosphere can improve biomass growth (Kimball & Idso, 1983), but the extent of this effect depends on the plant specie's physiology, especially whether the plant is a C_3 or C_4 species,[11] since that influences the way CO_2 is processed in the plant (Kimball & Idso, 1983; Reilly et al., 2001).

Since corn is a C_4 species, it is less sensitive to the effects of doubled CO_2 concentrations (Leakey et al., 2006). Opinions differ on whether the growth increase caused by elevated CO_2 levels will balance out the yield loss caused by higher temperatures. Early studies indicated that a doubling of the CO_2 concentration in the atmosphere could increase agricultural weight yield by up to 33% (Kimball & Idso, 1983), and some of the recent FACE[12] studies support these observations (Ziska & Bunce, 2007). Other research however shows that the effect of CO_2 enrichment on plants might be up to 50% less than expected (Long et al., 2006; Leakey et al., 2006).

Two studies conducted in glasshouses (Ziska & Bunce, 1997; Maroco et al., 1999) showed very different results in biomass increase. In a 30 day glasshouse study, Ziska and Bunce found a biomass increase for corn of 2.9% when the CO_2 concentration was increased from 38 Pa to 69 Pa (which correspond to 375ppm and 681ppm respectively, assuming standard atmospheric pressure of 101.325 kPa for the experiments). Maroco et al. found a 19.4% increase when increasing CO_2 levels from 350 to 1,100ppm and high light conditions.

The average of the before mentioned literature values for a CO_2 increase from 380ppm to 440ppm results in an expected biomass and yield increase of 1% (Hatfield et al., 2008). That would mean per 100ppm increase of CO_2 in the

[11] Almost all plant life on Earth can be divided into two categories based on the way they assimilate carbon dioxide into their systems. C_3 species continue to increase photosynthesis with rising CO_2. C_3 plants include more than 95 percent of the plant species on Earth. C_4 plants initially form four carbon-atom molecules. C_4 plants include such crop plants as sugar cane and corn. They are the second-most prevalent photosynthetic type, and do not assimilate CO_2 as well as C_3 plants. [Hatfield et al., 2008, p.195]

[12] Free-Air CO_2 Enrichment (FACE) technology has allowed evaluation of a few select crops to better understand their response under field conditions without enclosure-confounding effects (Hatfield et al., 2008, p.35).

atmosphere, corn yield would increase by 1.67%.

However, the evidence for the response of corn concerning both yield and biomass is sparse and research often results in contradictory outcomes. For this reason, the value of 1.67% per 100ppm CO_2 increase is only a start value for modeling and further research in this field is necessary.

vii. Alfalfa

Alfalfa is generally grown as a forage crop. It is a perennial legume that is commercially viable from 3 to 10 years (Russo et al., 2008; KSU, 1998) even though it can grow for over 20 years. Alfalfa is commercially grown in 43 states (see figure 17) (NASS/USDA, 2012). The top five states are South Dakota, California, Montana, Idaho, and Minnesota. It is grown in smaller amounts in the southern states where it is often attacked by leaf and root diseases. In 2011, 65 million tons of alfalfa hay was produced (see figure 18) (NASS/USDA, 2012).

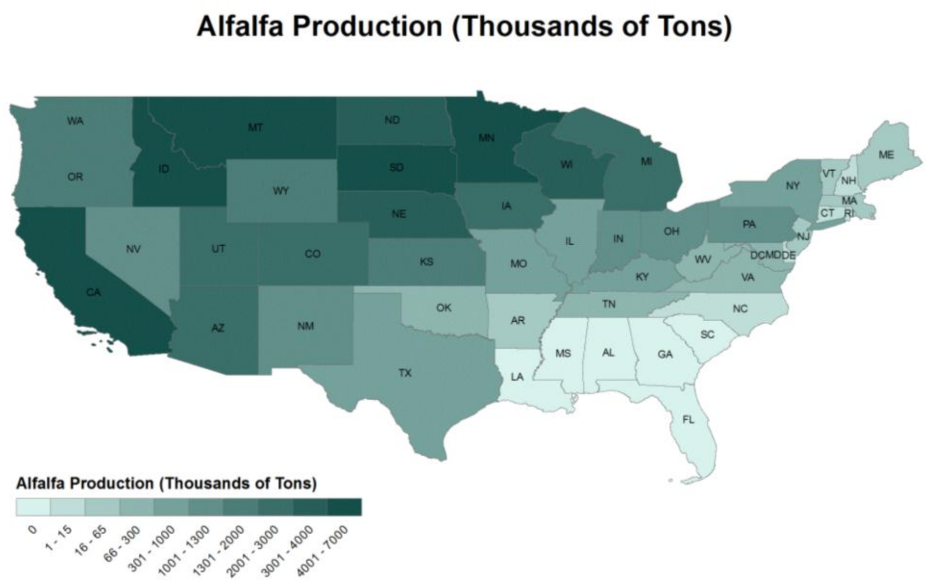

Figure 17: Alfalfa production in the United States. (NASS/USDA, 2012).

Common alfalfa varieties (*Medicago sativa ssp. Sativa)* grow upright with purple flowers (KSU, 1998). The variety is very important because this plant grows for a long period of time. When selecting a variety, farmers consider a number of factors including yield potential, disease and insect resistance, fall dormancy, and winter hardiness (KSU, 1998). This C_3 plant grows to around 3 feet in height. It is a nitrogen fixing plant with root nodules. While the crop can be high yielding with high nutritional content, it is a water intensive crop (Russo et al., 2008). Its profitability is highly dependent on water availability and costs. A farmer can obtain more alfalfa by watering the crop more during the growing period (Russo et al., 2008). While it is water dependent, alfalfa is a deep-rooted plant that is drought resistant (KSU, 1998).

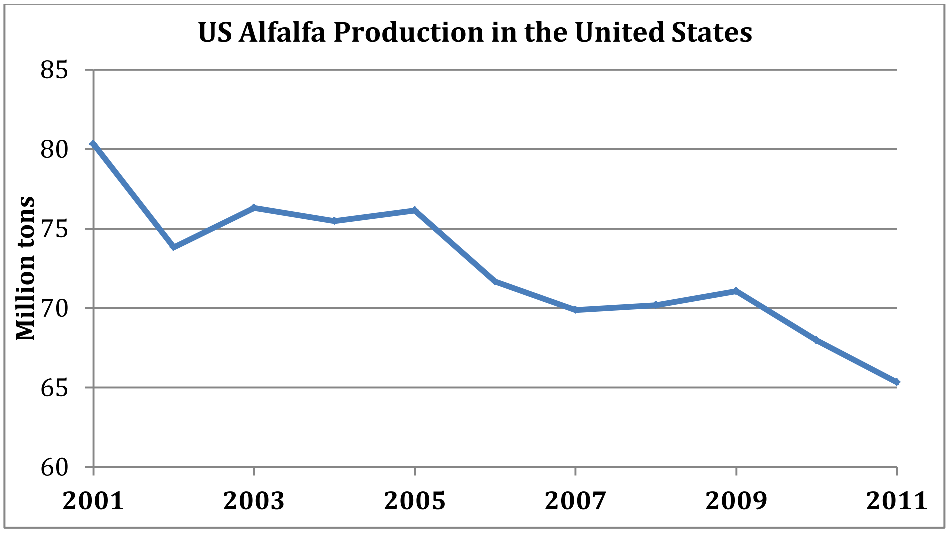

Figure 18: Total alfalfa and alfalfa mixtures production in the U.S. (NASS/USDA, 2012).

Alfalfa can be used as hay or made into silage. Of the common hay crops (alfalfa, clove, and grass), alfalfa has the highest commercial value. It can be harvested multiple times in one year, generating many returns for farmers. Alfalfa and its silage are one of the largest components of dairy cattle diets (UA & MTU, 2010). In California, around 70% of the total alfalfa supply was used by dairy farmers (Russo et al., 2008). Therefore, the size of the herd in California greatly affects the demand for alfalfa.

The Impacts of Climate Change on Alfalfa

As climate and CO_2 levels change, farmers can select varieties of alfalfa that do better in these conditions. Studies have shown alfalfa can improve yields due to increased temperature and carbon dioxide concentrations (Erice et al., 2011). The impact of climate change on overall alfalfa yields will depend upon the varieties farmers select.

As CO_2 increases, greater CO_2 concentrations will impact photosynthetic activity in plants. For C_3 plants, it is expected that photosynthesis will increase causing the productivity of plants to increase (Daepp et al., 2000). Studies have shown that productivity of C_3 pasture grasses and legumes will increase 10% and 20% respectively (Tubiello et al., 2007). Another study showed that doubling CO_2 concentrations cause C_3 crops to increase their average yields by 13-43% (Aranjuelo et al., 2006).

While productivity may increase, there are other factors such as water, nitrogen, and phosphorus that may limit the ability of plants to increase yields. The availability of water in the soil will affect how a plant responds to climate change (Volk et al., 2000). Water deficiency negatively impacts plant growth (Chaves et al., 2002), and it is predicted that climate change will increase water stress on crops in parts of the U.S. (IPCC, 2007). However, greater CO_2 in the atmosphere is expected to cause plants to use water more efficiently (Drake et al., 1997; Aranjuelo et al., 2006).

Since CO_2 causes plants to increase growth, the demand for nitrogen will increase. Plant response to climate factors, therefore, is expected to be limited by the availability of nitrogen in the soil (Erice et al., 2011; West et al., 2005). Alfalfa has the ability to fix nitrogen due to nodules on its roots. Nitrogen-fixing legumes such as alfalfa will increase their ability to fix nitrogen with higher concentrations of carbon dioxide (Rogers et al., 2006). Therefore, elevated carbon dioxide will cause growth to be greater in legumes than non-legumes unless there is insufficient phosphate, another plant limiting nutrient, in the soil (Ainsworth and Rogers, 2007).

While increasing CO_2 is expected to increase yields, temperature has been shown to negatively impact crop yields (Loebell & Asnet, 2003). In addition, the effect of plant growth due to temperature increases will be different depending on the growing season (Saez et al., 2012).

Experiments studying the impacts of climate change and an increase of CO_2 on alfalfa have shown varying results. Aranjuelo et al. placed alfalfa plants in greenhouse tunnels to study the effects of varying levels of CO_2 and temperature. They found that independent increases of either 4°C or 320 ppm CO_2 did not affect the yield of alfalfa. However, when the two factors were applied together, alfalfa dry matter increased by 38% (Aranjuelo et al., 2006). They conducted the same experiment under drought conditions. They found that higher CO_2 and temperatures increased yields of alfalfa under drought conditions (Aranjuelo et al., 2006).

Another experiment found alfalfa yields to increase by 8% with an extra 100 ppm of CO_2 in the atmosphere (Easterling et al., 1993). Saez et al. (2012) conducted a study growing alfalfa in gradient greenhouses. Plants were divided among two CO_2 levels (350 and 700 ppm) with two temperatures (ambient and +4°C). The results found that dry matter increased under elevated CO_2 and temperature for three different alfalfa strains. In addition, the results showed some strains were more productive than others. Similar to Aranjuelo et al. (2006), Saez et al. found that the interaction between CO_2 and temperature increased plant growth.

As stated previously, the effects of climate change vary regionally. The effects of climate change were modeled for California and found that the change in alfalfa yields will be between -0.3 and 4% by 2050 under the A2 and B1 climate scenarios (Lee et al., 2011). The model found the differences between the scenarios to be less than 1% for alfalfa. The model also predicted alfalfa yields to increase a further 5% by 2094. Alfalfa was the only grain crop that showed yield improvements through 2094. The change in yields varied drastically by county from -10% to 14% (Lee et al., 2011). Another study conducted for one Californian county found that alfalfa yields under B1 and A2 to be unchanged in 2050 (Jackson et al., 2011). Therefore, studies have shown a large variability in alfalfa responses to climate change.

viii. Climate change impacts on fuel and electricity prices

Agricultural products are not the only dairy inputs that will be influenced by a changing climate. Fuel and electricity prices, for example, might be impacted by climate change in many different ways. Thermal power plants become less efficient with an increase in ambient air temperatures and hydropower plants will also be strongly affected since they depend on snow melt and precipitation. Climate change is expected to impact renewable energy sources such as photovoltaic and wind power due to changes in wind patterns, cloud cover and solar radiation (Argonne, 2012).

Another area of climate change impact is the energy demand for space heating and cooling. Warmer temperatures during the summer increase the electricity need for air conditioning and refrigeration, while warmer temperatures in cold areas during the winter will reduce heating needs (Argonne, 2012).

Since most of the transport of crude oil and processed petroleum product is moved by ocean vessel or pipeline, fuel transportation and production is also receptive to climate change. It can be impacted both by short-term extreme weather events as well as long-term climatic shifts in regional changes such as precipitation or snowmelt (Wilbanks et al., 2008).

Snowmelt and precipitation can influence river flow and navigable periods. Extreme climatic events such as hurricanes and tsunamis can impose severe damages to offshore pipelines and oil platforms (Wilbanks et al., 2008).

II. Methods Dairy Model

A. Motivation

The literature review showed a surprising lack of research on the impacts of climate change on dairy production. The few studies that modeled the effect of climate change on dairy regions only investigated a limited number of inputs. One study looked at heat stress on cows alone while another looked at only a particular crop that was regarded as one of the main feed sources for the dairy cows in that region. This available research also lacked confounding factors such as the effects of increasing CO_2 levels on crop yields and impacts of the increasing frequency of severe storm events. These findings led to the conclusion that a model should be constructed to combine many of the researched effects of climate change and their corresponding effect on the U.S. dairy industry.

B. Goal

The goal of the dairy model is to predict the cumulative quantitate effect of climate change on the total operating costs of a representative dairy farm. To determine the total increase in operational costs, the effects of climate change on a dairy farm's critical inputs needed to be measured individually and aggregated into a single figure to find the total change in operating costs.

C. Scope and Scale

To determine the scope of the model, all the major inputs to a representative intensive dairy farm were assembled through personal interviews with industry experts, literature research, and the development of a conceptual model. The major inputs were separated into three categories: physical, natural, and regulatory.

Table 6: Preliminary identified inputs

Physical	Natural	Regulatory
Feed	Precipitation	Local
Purchased Feed	Temperature	Regional
Homegrown Feed	Solar Radiation	National
Water	Soil Geology	
Fertilizer	Latitude	
Seeds	Local Water Resources	
Energy		
Electricity		
Fuel		
Overhead		
Labor		
Machinery/Equipment		
Veterinary Medicine		

Three different evaluation criteria were used to select the inputs for the model. The criteria used were the following:

1. Input must constitute a large portion of a dairy farm's budget.
2. Input must be directly affected by climate change.
3. Input must be measurable with a high level of certainty.

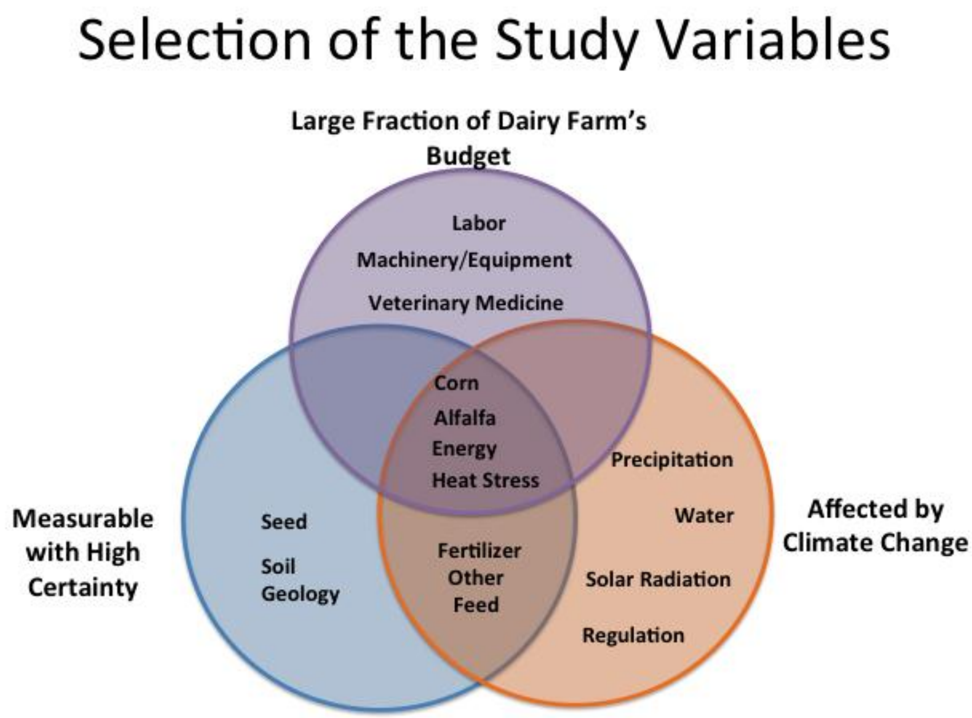

Figure 19: Venn diagram of inputs affected by climate change.

Using the before mentioned evaluation criteria, it was possible to narrow the project's scope to the six most important dairy farm inputs that fulfill the criteria:

1. Corn
2. Corn Silage
3. Alfalfa
4. Alfalfa Silage
5. Fuel/Electricity
6. Temperature

As stated earlier in the report (see figure 5 in section I. A. v.), the United States was divided into five separate geographical regions. The Innovation Center for U.S. Dairy, who supplied this project with feed input data for a dairy farm, made these regional distinctions in their latest Life Cycle Analysis for a gallon of milk (UA & MTU, 2010).

D. Data Sources

i. Climate Data

In this analysis, an A2 climate scenario was used to investigate the impacts of climate change in 2050. Using information from the IPCC scenario map of the United States, the average temperature for each region was estimated. For CO_2 concentrations, it was assumed that there are no regional differences and a national concentration from the IPCC for all five regions was used.

Table 7: Temperature and CO_2 increases by region

	Temperature Increase, °F	Temperature Increase, °C	PPM Increase
Region 1	4.50	2.50	525
Region 2	3.80	2.11	525
Region 3	4.50	2.50	525
Region 4	4.50	2.50	525
Region 5	4.00	2.22	525
National	4.26	2.37	525

ii. Climate Change Effect on Crop Yield

Using the aforementioned research on crop yields response, it was possible to estimate the effects of both increasing temperature and CO_2 on crop yields. Though alfalfa yields and climate change have not been studied as readily as corn, estimates could be used for the model. As follows are the national averages used in this model.

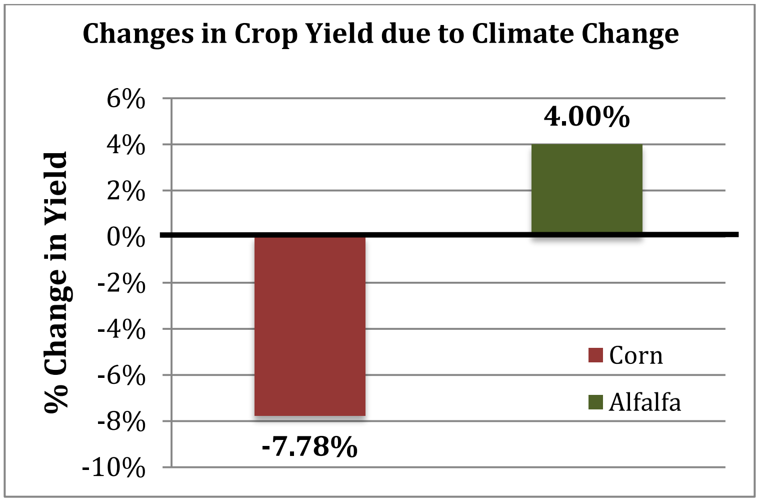

Figure 20: Changes in crop yields due to CO_2 and temperature increases.

Due to the fact that these yield changes are by quantity and the equation looks at changes in production cost, these values need to be converted to dollars. In order to accomplish this, the elasticity of supply equation below was used.

$$\%\ \boldsymbol{change\ in\ price} = \%\ \boldsymbol{change\ in\ yield} \cdot \boldsymbol{elasticity\ of\ supply}$$

In order to use this equation, it was assumed corn and alfalfa production were distributed equally across the five regions. Using this assumption the national average of temperature and $C0_2$ change were used to determine the national change in alfalfa and corn prices. In addition, the average of published values for the elasticity of supply for corn and alfalfa was used in the model.

Table 8: Elasticity of Supply Estimates (Gardner, 1976; Nerlove, 1953)

	Low	High	Average
Alfalfa	0.25	0.29	0.27
Alfalfa Silage	0.25	0.29	0.27
Corn	0.24	0.28	0.26
Corn Silage	0.24	0.28	0.26

iii. Composition of Feed

The composition of alfalfa, alfalfa silage, corn, and corn silage was determined for each region using the Innovation Center for U.S. Dairy's LCA data on feed.

Using costs of each component, a total percentage of feed by cost was determined.

Table 9: Percentage of each crop in total feed by cost by region (UA & MTU, 2010).

	Region 1	Region 2	Region 3	Region 4	Region 5
Alfalfa	10.75%	1.39%	3.39%	14.18%	20.53%
Alfalfa Silage	11.30%	2.44%	11.62%	9.90%	2.06%
Corn	32.82%	35.34%	45.66%	42.28%	26.58%
Corn Silage	22.33%	5.02%	15.07%	10.07%	13.12%

Home Grown vs. Purchased

There is limited data on the percentage of feed that is grown on dairy farms versus the percentage of feed that is purchased. To estimate the percentage of home grown vs. purchased feed, data from the USDA's production costs were used. The USDA separately lists the amount of money spent on purchased and home grown feed. The percentage of homegrown and purchased was calculated from the total amount spent on feed. The USDA provides data for 23 states, which are generally the largest in milk production. The breakdown of homegrown versus purchased feed for each region was calculated by averaging the costs for the available states in each region.

Table 10: Purchased vs home grown feed (USDA, 2011)

	Purchased	Home Grown
Region 1	72.31%	27.69%
Region 2	65.55%	34.45%
Region 3	51.09%	48.91%
Region 4	84.23%	18.42%
Region 5	81.92%	17.32%

iv. Energy

The effect of climate change on fuel prices was estimated from electricity and energy prices. A study by Amato et al. found that the national average of electricity prices would increase by 3% by 2050 due to climate change (Amato et al., n,d). This value was used as an estimate for the high scenario because a higher value could not be found. The study also forecasts the increase of oil prices to be 15% by 2050 on average with a possible maximum of 83%. Due to a lack of specific energy use data, it is assumed that the representative dairy farm's energy budget is split evenly between electricity and fossil fuel.

Table 11: Energy price increases (Amato, n,d)

	Average	High
Fuel	15%	83%
Electricity	3%	3%
Total	9%	43%

v. Heat Stress

Heat stress was included in the model due to its potentially significant effect on productivity. A decrease in milk output with the same financial inputs will result in a direct increase in total overall operating expenses. To determine the effect of heat stress on milk yield, a series of studies that quantified this relationship were utilized.

The first study by Klinedinst et al (1993) titled "The Potential Effects of Climate Change on Summer Season Dairy Cattle Milk Production and Reproduction" looked at the effects of a warming climate on European and American dairy cows. This study only looked into a warming climate's effect on yearly production. It is also important to note that the authors only looked into the direct effects of a warming climate and not the indirect effects on inputs such as feed and water availability (Klinedinst, 1993).

To quantify the relationship between heat stress and dairy production the authors used a commonly accepted and tested model by Berry et al. (1964). This model uses both temperature and humidity to calculate the loss in normal production levels of a given dairy cow. The equation is displayed below:

$$\boldsymbol{MPD} = -\mathbf{1.075} - \mathbf{1.736} \cdot \mathbf{NL} + \mathbf{0.02474} \cdot \mathbf{NL} \cdot \mathbf{THI}$$

Where
NL= normal production levels, kg/(cow x day)
THI = temperature humidity index
MPD = the absolute decline in milk production, kg/(cow x day)

$$\boldsymbol{THI} = \boldsymbol{T_{db}} \cdot \mathbf{0.36} \cdot \boldsymbol{T_{dp}} + \mathbf{41.2}°\boldsymbol{C}$$

Where
T_{db} = dry bulb temperature, °C
T_{dp} = dew point temperature, °C

In addition to this stress model, the authors also took into consideration the possibility of declining conception rates with rising temperature. They used the conception rate model created by Ingraham (1974) and Hahn (1981). This equation is as follows:

$$\boldsymbol{CR = 388.3 - 4.62 \cdot THI}$$

Where
CR = conception rate, % of delivered cows

Long-term monthly averages for both humidity and temperature were used in each location. Two different milk production levels were tested in their sensitivity to warming summer temperatures. In addition, three Global Circulation Models were used to predict the amount of warming in each geographical location: Goddard Institute for Space Studies (GISS), Geophysical Fluid Dynamics Laboratory (GFDL), and United Kingdom Meteorological Office (UKMO). The expected milk yields were summed over each production season with and without these climate scenarios.

In this paper, Klinedinst et al. found that there would be significantly greater loss in milk production in the United States then in Europe. The greatest decline was seen in the Southeastern and Southwestern United States. However, it was noted that these areas are already accustomed to production declines in the summer time, so the impacts might in fact be greater in the Midwest and northeast where proper mitigation measures might not yet be in place. As follows are the production declines for each of the dairy regions using representative cities from the before mentioned paper (Klinedinst, 1993).

Table 12: Milk yield decrease due to heat stress (Klinedinst, 1993).

	Milk Yield Decrease
Region 1	0
Region 2	10.25%
Region 3	5.79%
Region 4	8.85%
Region 5	8.30%

An additional study done in Australia titled "Managing hot cows in Australia" by Davison et al. (1996) looked into how heat stress affected cattle in New South Wales and Queensland. They measured heat stress using a Temperature Humidity Index. The index was calculated as

$$THI = T_{max} + 0.36 \cdot T_{dewpoint} + 41.2°C$$

Where

$$T_{dewpoint} = \frac{273 \cdot \frac{VP}{6.107}}{17.269 - ln\left(\frac{VP}{6.107}\right)}$$

The authors found that a cow's milk yield starts decreasing when the Temperature Humidity Index reaches 72. They investigated three separate management techniques and found their resulting impact on milk yields. The results are shown in the following table:

Table 13: THI thresholds leading to stress under different management techniques (Davison et al., 1996).

Management	Poor	Average	Good	Best
Cooling Strategy	Nil	Some Shade	Shade at Feed	Shade & Sprinklers
THI Threshold	72	74	76	78

Another study titled "Climate change impacts in the Hunter Valley" by the CSIRO Atmospheric Research Group looked into how heat stress is affecting dairy cows (Jones et al., 2000). This study looked at a specific location of Hunters Valley in New South Wales. The authors used the same temperature humidity index as used in Australia by Davison et al. They investigated a business as usual scenario and one with mitigation measures in place. These mitigation measures included the construction of shade and sprinkler systems in areas of extreme warming. As follows are the milk yield declines with and without mitigation techniques.

Table 14: Yield Loss With and Without Heat Stress Mitigation (Jones et al., 2000).

	2010	2030	2070
Production Loss (No Mitigation)	3.30%	3%	6%
Production Loss (Mitigation)	0.80%	0.10%	3.50%

Given this research, the values from Peggy et al. (1993) were selected as the most suitable ones for the purpose of this report to predict heat stress by region. An assumption was made that farmers would not use any heat stress mitigation techniques. The cost of these techniques varies by location and is very difficult to estimate regionally. For a more in depth analysis, a specific farm needs to be selected to study. This specific analysis will allow a modeler to account for microclimates and local resources that vary significantly throughout each region.

It is important to note that in a recent paper entitled "Quantifying Heat Stress and Its Impact on Metabolism and Performance", Collier et al. (2012) found a more intense relationship between milk yield and temperature. This was explained by the need of heat stress proteins in mammals experiencing higher than normal temperatures. The author's main finding was that metabolic heat output and milk production levels are linked. Given this fact they assert that the higher milk production levels of today are making cows more susceptible to heat stress then earlier estimates might suggest. The authors found cows were already affected by heat stress at a temperature humidity index of 65. This is significantly higher than the THI of 72 which has been thought of as the heat stress threshold in the past.

E. Model

Figure 21: The conceptual model created by the project members.

To determine the increase in operational costs to a dairy farmer due to climate change, a model was constructed that included all the critical inputs discussed in this report (see figure 21). In order to combine the effects of the aforementioned inputs, the model was split up into three formulas to calculate how changes in these inputs affect the total operating budget of a representative dairy farm.

vi. Change in Feed Costs

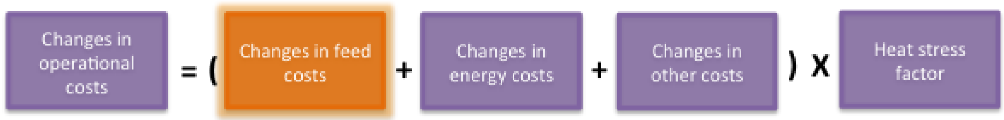

Figure 22: The conceptual model highlighting the changes in feed costs component of the model.

To determine the total change in feed costs, the changes in homegrown feed costs were added to the changes in purchased feed costs. In order to determine the change in crop prices in both scenarios, it was necessary to establish a relationship between yield and price. This first equation below determines the change in crop price given a change in yield. This equation is a function of temperature change, yield change, and supply elasticity.

$$\%\ \boldsymbol{change\ in\ crop\ price} = \frac{(\boldsymbol{T_x} \cdot \boldsymbol{Y_a}) + (\boldsymbol{C_x} \cdot \boldsymbol{Y_a})}{\boldsymbol{E_a}}$$

Where:

T_x = Temperature increase in degrees C for region X
Y_a = Yield change per degree C temperature increase for crop A
C_x = CO2 increase in 1 parts per million increase in region X
Y_a = Yield change per degree C temperature increase for crop A
E_a = Elasticity of supply for crop A

Next, to determine the change in the feed budget due to an increase in purchased feed costs, the following equation was used. It is important to note that crop prices were averaged nationally due to a consolidated national market for feed.

$$\boldsymbol{FBC_b} = ((\boldsymbol{C_a} \cdot \boldsymbol{FP_{na}}) + (\boldsymbol{C_{as}} \cdot \boldsymbol{FP_{nas}}) + (\boldsymbol{C_c} \cdot \boldsymbol{FP_{nc}}) + (\boldsymbol{C_{cs}} \cdot \boldsymbol{FP_{ncs}}))$$

Where:

FBC_b = % change in purchased feed budget
C_a = % of Alfalfa in total daily diet in region X

FP_{na} = National change in alfalfa price
C_{as} = % of Alfalfa Silage in total daily diet in region X
FP_{nas} = National change in alfalfa silage price
C_c = % of Corn in total daily diet in region X
FP_{nc} = National change in corn price
C_{cs} = % of Corn Silage in total daily diet in region X
FP_{ncs} = National change in corn silage price

As follows is the change in feed budget due to an increase in homegrown costs. This equation assumes farmers will increase their home production to meet any loss in yield at a new more expensive per unit price.

$$\boldsymbol{FBC_h} = \begin{bmatrix} \boldsymbol{HG_a}\left(-\mathbf{1} + \dfrac{\mathbf{1}}{\mathbf{1} + \boldsymbol{CYL_a}}\right) + \boldsymbol{HG_{as}}\left(-\mathbf{1} + \dfrac{\mathbf{1}}{\mathbf{1} + \boldsymbol{CYLas}}\right) \\ + \boldsymbol{HG_c}\left(-\mathbf{1} + \dfrac{\mathbf{1}}{\mathbf{1} + \boldsymbol{CYL_c}}\right) + \boldsymbol{HG_{cs}}\left(-\mathbf{1} + \dfrac{\mathbf{1}}{\mathbf{1} + \boldsymbol{CYL_{cs}}}\right) \end{bmatrix}$$

Where:

FBC_h = % Increase in home grown feed budget
HG_a = % of Alfalfa in total home grown budget in region X
CYL_a = Alfalfa yield loss in region X
HG_{as} = % of Alfalfa in total home grown budget in region X
CYL_{as} = Alfalfa Silage yield loss in region X
HG_c = % of Corn in total home grown budget in region X
CYL_c = Corn yield loss in region X
HG_{cs} = % of Corn Silage in total home grown budget in region X
CYL_{cs} = Corn Silage yield loss in region X

Putting all these equations together results in the total change in the feed budget.

$$\boldsymbol{FBC_b} = \boldsymbol{F_p} \cdot \sum(\boldsymbol{C_x} \cdot \boldsymbol{FP_{nx}}) + \boldsymbol{F_h} \sum(\boldsymbol{HG_x} \cdot \boldsymbol{A})$$

where:

FBC_b = % Increase feed budget

F_p = % of feed purchased
F_h = % of feed home grown
C_x= % of composition of crop x in purchased budget
HG_x= % of composition of crop x in homegrown budget
FP_{nas} = National change in crop x price
A = Region X change in homegrown unit price

vii. Change in Energy Budget

Figure 23: The conceptual model highlighting the changes in energy costs component of the model.

The change in energy costs is a function of both the increase in fuel and electricity prices. In the analysis, a 50-50 weight was assumed because the data available did not itemize the energy budget for the regional representative dairy farms. This weight can easily be adjusted with individual farm data.

$$E_c = W_{fc} \cdot \mathrm{FCC} + W_{ec} \cdot \mathrm{ECC}$$

E_c = Total Energy budget
W_{fc} = Fuel weight
FCC = Fuel Cost Change
W_{ec} = Electricity Weight
ECC = Electricity Cost Change

viii. Overall Equation

Figure 24: The conceptual model highlighted by color.

The overall equation is stated below. This equation includes the effects of changing feed costs, changing energy costs, and heat stress on the total production costs to a representative dairy farm. It is important to note that heat stress is a decrease in yield given the same monetary inputs thus effectively increasing production costs.

$$\boldsymbol{P_c} = \frac{((\boldsymbol{FB_c} \cdot \boldsymbol{W_f}) + (\boldsymbol{E_c} \cdot \boldsymbol{W_e}) + (\boldsymbol{O_c} \cdot \boldsymbol{W_o}) + \mathbf{1}}{\mathbf{1} + \boldsymbol{HS_x}} - \mathbf{1}$$

P_c = % Change in Operational Costs
FB_C = Total feed budget change
W_f = % of Feed budget in total budget
E_C = Total energy budget change
W_e = % of energy budget in total budget
O_C = Total overhead budget change
W_o = % of overhead budget in total budget
HS_x = Heat Stress for region X

F. Case Study

To illustrate how the proposed model can be used by an individual farmer, a case study was developed. Average values found in the literature for each one of the model input parameters were used. These values included predicted temperatures in the year 2050 for a hypothetical dairy farm in Fresno, CA. The parameters used in the case study are found in table 15.

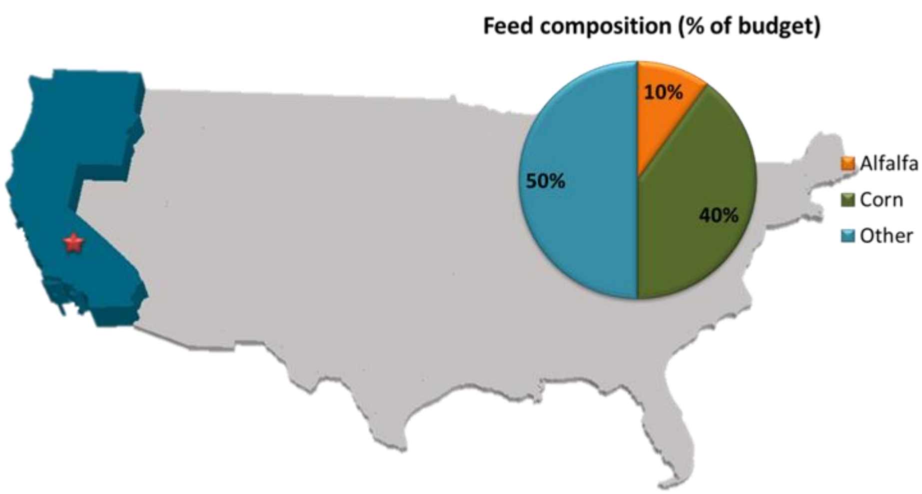

Figure 25: Breakdown of feed for the case study.

Table 15: Parameters used in the case study

Parameter Description	Parameter Value
Milk yield (per cow per year)	22,000 lbs
Feed costs (percentage of total budget)	58.76%
Percentage of purchased feed	90%
Feed composition	Corn 40%, Alfalfa 10%, Other 50%
Energy costs (percentage of total budget)	3.6%
Regional energy price increase to 2050	21.4%
Heat Stress (average daily temperature in the summer at the year 2050)	31.3°C

i. Case Study Results

Based on the parameters above, the model found a 10.3% increase in production costs to the farm. The main factors contributing to the change in costs are a 22.2% increase in corn prices and a 4.2% decrease in milk yield due to heat stress. Figure 26 shows, that the inputs causing the greatest increase in production costs are feed and heat-stress.

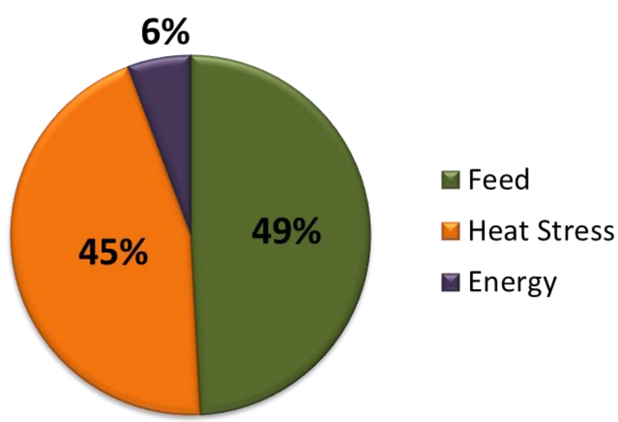

Figure 26: The percentage contribution to the total operational costs change.

III. Results & Analysis

Due to the high uncertainty of the values found during the literature review, three scenarios were developed to represent the different degrees of response of the four model parameters (corn, alfalfa, fuel and electricity prices, and heat stress) to climate change. A low response scenario used the lowest cited values and in some times reduced them by a factor of 50%. The medium response scenario used average values found during the literature review, and the high response scenario used the highest cited values and in some times increased them by a factor of 100%. Furthermore, heat stress is expected to affect all regions except region one. Climate change is expected to cause a decrease in corn yields and an increase in alfalfa yields.

For each of the scenarios, the change in costs for the studied variables (corn prices, alfalfa prices, electricity and fuel prices and heat stress) was adjusted. All scenarios were executed for each region.

Table 16: Input values used for the different scenarios

Region	Scenario	Heat Stress	Alfalfa Yield	Corn Yield	Fuel	Electricity
1	Low	0%	0%	-1.58%	0%	0%
	Medium	0%	1.15%	- 6.65%	15%	3%
	High	5.00%	2.28%	-8.31%	83%	3%
2	Low	2.56%	0%	-.84%	0%	0%
	Medium	5.12%	0.97%	- 5.42%	15%	3%
	High	10.25%	1.93%	-6.82%	83%	3%
3	Low	1.45%	0%	-1.58%	0%	0%
	Medium	2.89%	1.15%	- 6.65%	15%	3%
	High	5.79%	2.28%	-8.31%	83%	3%
4	Low	2.21%	0%	-1.58%	0%	0%
	Medium	4.43%	1.15%	- 6.65%	15%	3%
	High	8.85%	2.28%	-8.31%	83%	3%
5	Low	2.07%	0%	-1.05%	0%	0%
	Medium	4.15%	1.02%	- 5.77%	15%	3%
	High	8.30%	2.03%	-7.25%	83%	3%
National	Low	1.66%	0%	-1.32%	0%	0%
	Medium	3.32%	1.09%	- 6.23%	15%	3%
	High	7.64%	2.16%	-7.80%	83%	3%

A. Low Response Scenario

The low response scenario models mild impacts on milk yield from heat-stress, small increases in corn prices, and no change in alfalfa or energy prices.

i. Scenario Parameters

Heat Stress: Under the low response scenario, we used values that are 50% below the values published by Peggy et al (1993).
Region 1 – 0.00%
Region 2 – 2.56%
Region 3 – 1.45%
Region 4 – 2.21%
Region 5 – 2.07%

Corn Prices: 5% increase in corn prices to the farmers across all regions due to climate change impacts to that crop.

Alfalfa Prices: No change in alfalfa prices

Energy and Electricity Prices: No changes in electricity and fuel prices.

ii. Results

Based on the low response scenario, the average increase in production costs across all regions was 2.7%. Region 4 experiences the highest increase in production costs (3.5%), mostly due to increase in feed prices. In region 1, the increase in feed prices is responsible for nearly 100% of the production cost increase. The increase in production costs in regions 4 and 5 is almost equally split between heat-stress and increases in feed prices. No effects of heat-stress are expected to occur in region 1 by the year 2050 (under the low response scenario). Conversely, 80% of the increase in production costs in region 2 is due to the effects of heat-stress. In region 4, 68% of the increase in production cost is also due to the effects of heat-stress.

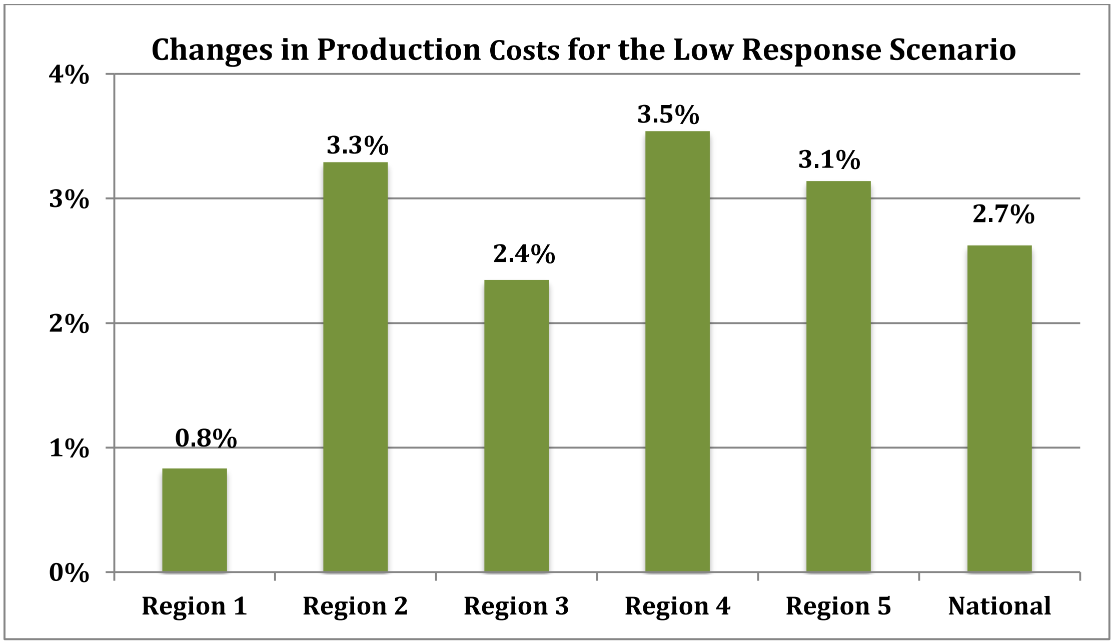

Figure 27: Results from the low response scenario.

B. Medium Response Scenario

The medium response scenario used average values found in research that are based on projected yields, price increases, and heat-stress impacts.

i. Scenario Parameters

Heat Stress: Under the medium response scenario, the following values published by Peggy et al. (1993) were used.
Region 1 – 0.00%
Region 2 – 5.12%
Region 3 – 2.89%
Region 4 – 4.43%
Region 5 – 4.15%

Corn Prices: 24% increase in corn prices (derived from multiple peer reviewed sources).

Alfalfa Prices: 4% decrease in alfalfa prices.

Energy and Electricity Prices: 9% increase (1.5% from electricity prices plus 7.5% from fuel price increases) (derived from Amato et al., 2005; EIA, 2012).

ii. Results

Based on the medium response scenario, the average increase in production costs across all regions is 8%. Region 4 experiences the highest increase in production costs (10.7%), mostly due to increase in corn and fuel prices. In region 1, the increase in feed prices is responsible for 92% of the production cost increase. The increase in production costs in regions 4 and 5 is almost equally split between heat-stress and increases in feed prices. No effects of heat-stress are expected to occur in region 1 by the year 2050 (under the medium response scenario). Conversely, 62% of the increase in production costs in region 2 is due to the effects of heat-stress. In region 4, 46% of the increase in production cost is also due to the effects of heat-stress.

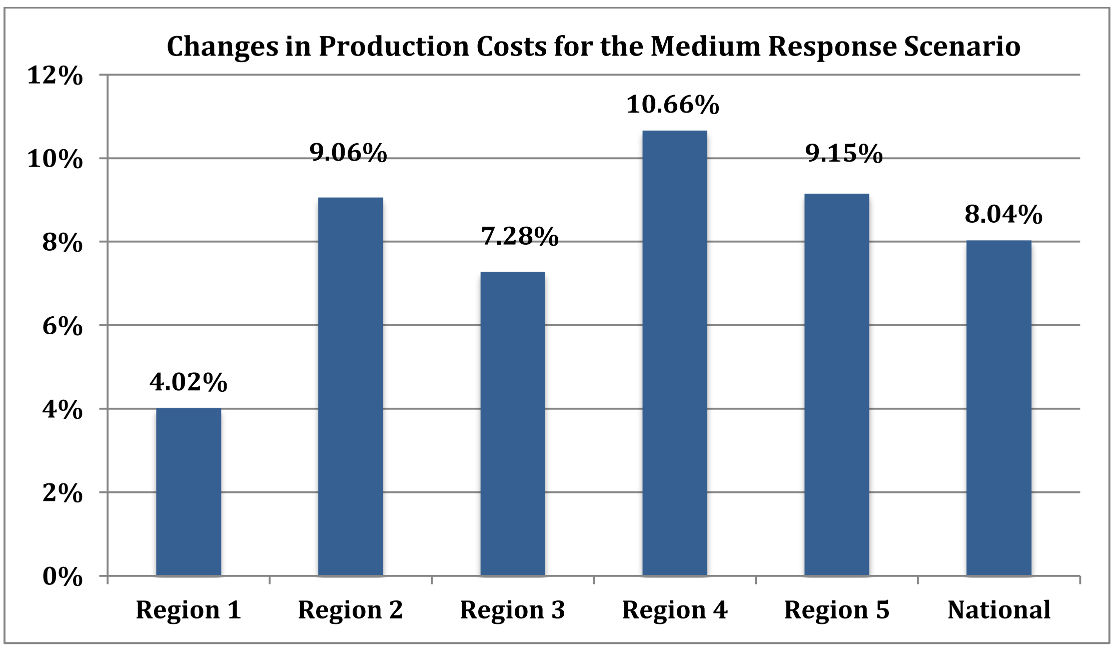

Figure 28: Results from the medium response scenario.

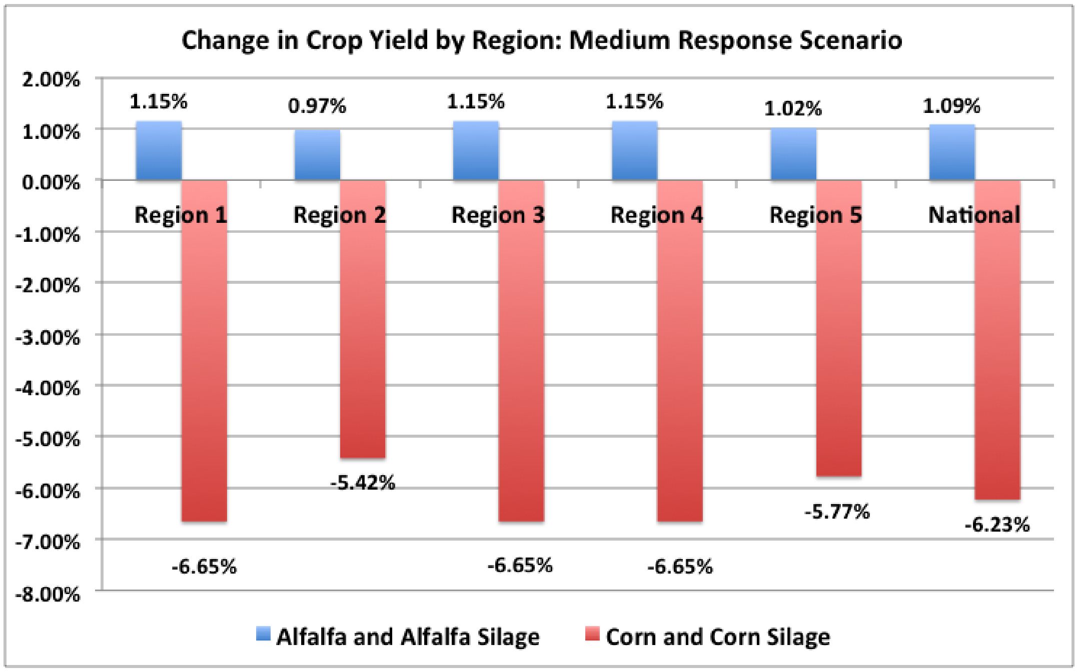

Figure 29: Change in crop yields by region.

Figure 29 illustrates how corn and alfalfa are expected to react from climate change. While alfalfa yields are expected to increase about 1% under the medium response scenario, corn yields are expected to decrease by 5.4% to 6.7% depending on the region.

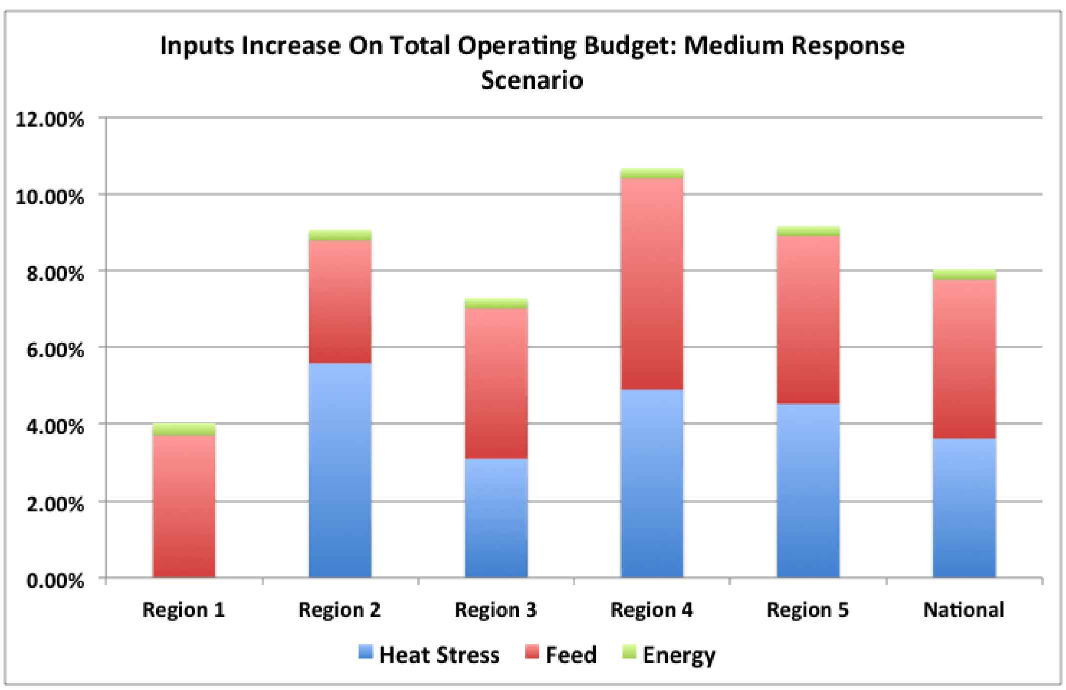

Figure 30: The breakdown of the operational cost increase by region

As it was previously discussed, figure 30 illustrates the compositions of the expected increase in operational costs for each region and the national average. Region 1 has no evidence of heat stress and most of the increase in operational costs is due to increase in feed prices. Region 2 suffers the most impact from heat stress. The change in energy price has a minimal effect on the total change in operational costs.

C. High Response Scenario

The high response scenario used values of projected price increases and impacts of heat stress that are higher than the values found during the literature review process.

i. Scenario Parameters

Heat Stress: Under the high response scenario, values published by Peggy et al. (1993) were doubled.
Region 1 – 5.00%
Region 2 – 10.25%
Region 3 – 5.79%
Region 4 – 8.85%
Region 5 – 8.30%

Corn Prices: 30% increase in corn prices (Liu Xiaohe, N.D.)

Alfalfa Prices: 8% decrease in alfalfa prices.

Energy and Electricity Prices: 43% increase (1.5% from electricity prices and 41.5% from fuel price increases) (derived from Amato et al. 2005; EIA, 2012).

ii. Results

Based on the high response scenario, the average increase in production costs across all regions is 15%. Region 4 experiences the highest increase in production costs (18.3%), mostly due to heat-stress. Under the high response scenario, all regions are affected by heat stress. In regions 1 and 3, roughly 50% of the increase in production costs was due to heat-stress. For this scenario we assumed a 5% efficiency loss due to heat stress in region 1. The 8% decrease in alfalfa prices did little to arrest the increases in corn and energy prices as well as the compounding effect of heat stress.

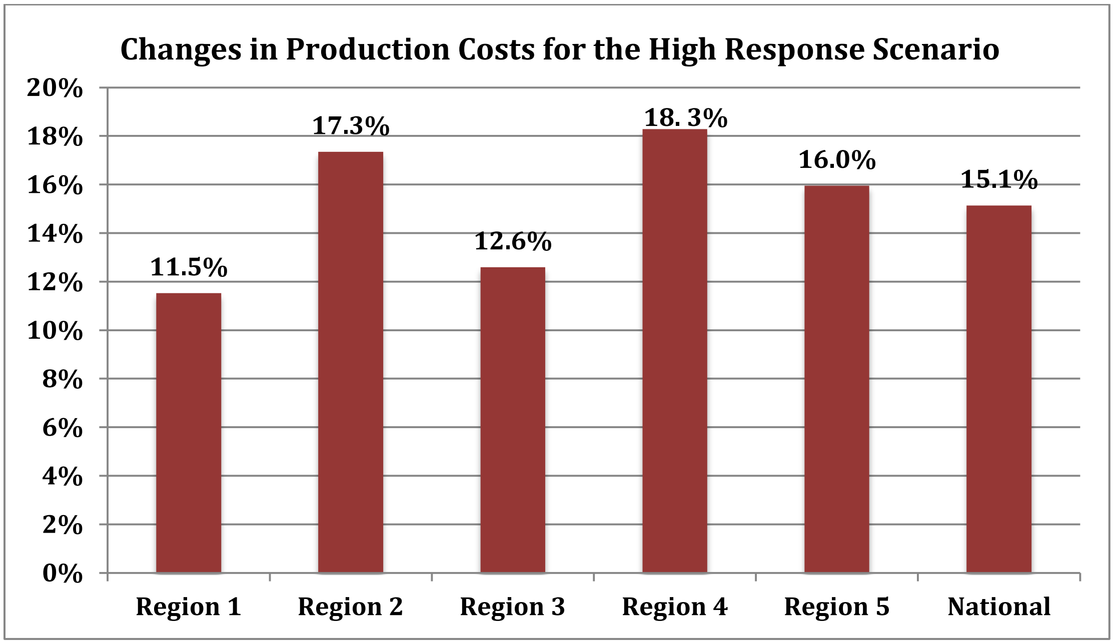

Figure 31: Results from the high response scenario.

D. Sensitivity Analysis

To evaluate the sensitivity of the proposed model to changes in each parameter, a sensitivity analysis was conducted. The first step was to run a baseline model using the parameters described in the medium response scenario (section III. B. ii.).

The orange line (mainly covered by the purple and grey lines) in figure 32 shows the baseline results for the increase in operational costs in the national average under the medium response scenario.

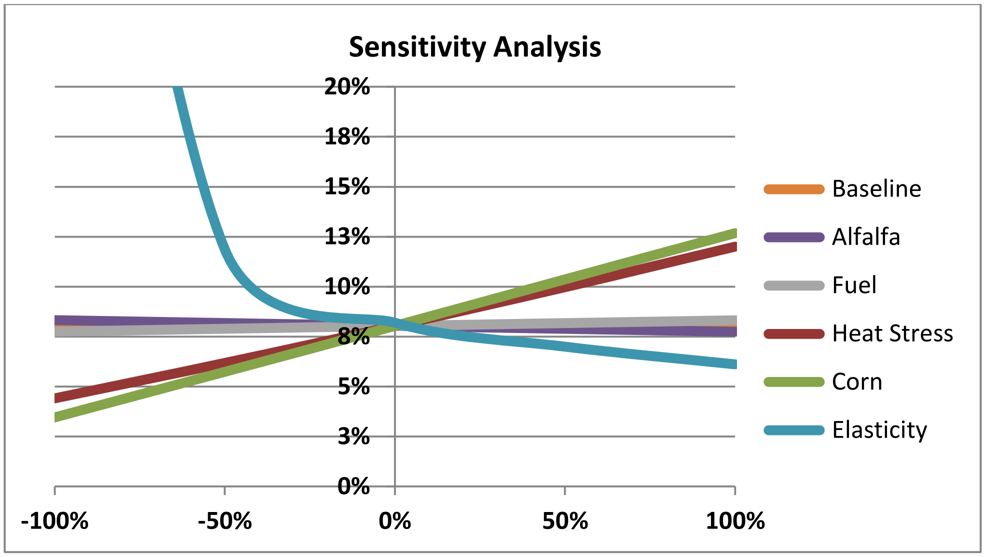

Figure 32: Results from the sensitivity analysis.

To find the sensitivity of one parameter, all parameters were held constant while one parameter was varied. The purple and grey lines in figure 32 show that the proposed model is not sensitive to changes in prices of alfalfa and fuel. This low sensitivity is mainly due to the fact that alfalfa and fuel represent only a small percentage of the average dairy farm's budget.

The red line in figure 32 shows the model is more sensitive to heat stress. Due to the large effect of heat stress on milk yields, the model is more sensitive to changes in the heat stress parameter. Doubling the heat-stress parameter, leads to an increase in production costs from 8% to almost 13%.

The green line in figure 32 shows the effects of corn on the model. Once again, all parameters are held constant, except the price of corn. By increasing corn yield loss by 100%, the average increase operational costs rose from 8% to 13%.

Finally, a sensitivity analysis was conducted for the elasticity of supply for feed (corn and alfalfa). The blue line in figure 32 shows that the model is extremely sensitive at low elasticity values (i.e. inelastic supplies of feed). Moreover, model results for very low elasticity values show increases in operational costs approaching infinity. The model's assumption is that farmers would continue to buy feed regardless of the price increase. As noted in the limitations of the model (section E), this is not a realistic assumption. At a certain point, adaptation strategies, including feed substitution, will be adopted by the farmers.

E. Discussion

It is extremely hard to predict how climate change will affect future yields and prices of crops (corn and alfalfa) and fuel and energy prices. The objective of the developed model was to determine the effects of climate change on the critical inputs to an intensive dairy farm, and to quantify how such changes will affect the total production costs of the farm. Three scenarios were developed to represent different levels of response to climate change for each critical input. Finally, the model incorporated heat stress in the total operating costs of the farm.

Each one of the parameters included in the model may react to climate change in different ways. To better represent the different possible outcomes, three scenarios were developed. The baseline scenario (medium response) assumes that the model parameters will react to climate change as predicted by average values found in the literature reviewed. To account for uncertainty in the parameters, we have developed two additional scenarios, a low response scenario, which assumes that parameters will not be greatly affected by climate change, and a high response scenario, which assumes that the model parameters' reaction to climate change will be at the high end of published values.

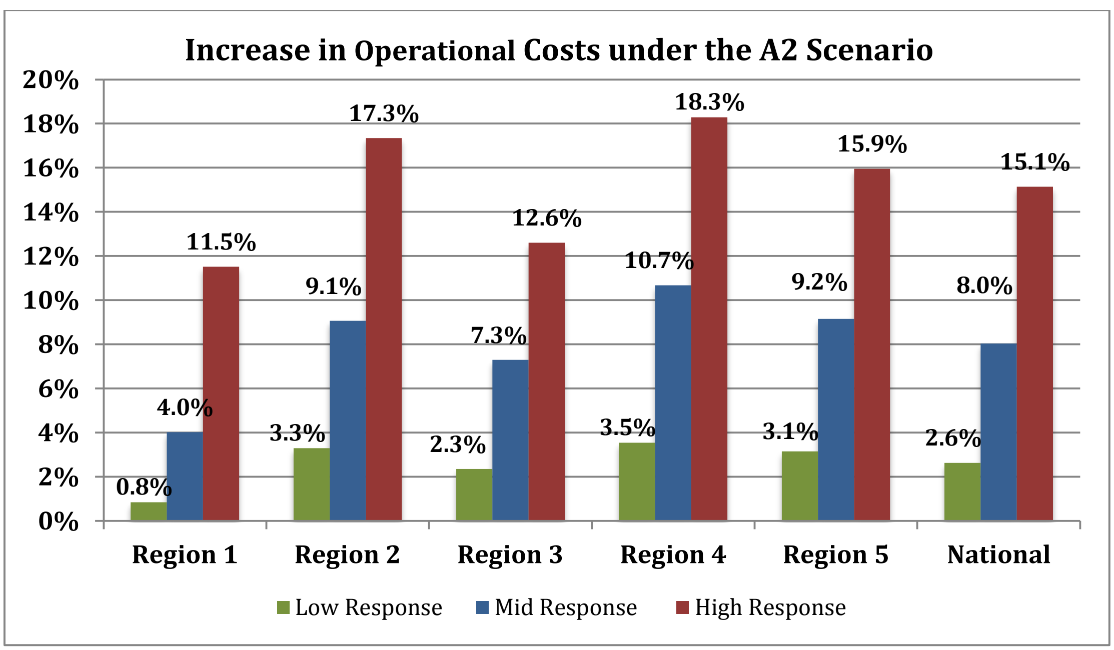

Figure 33: Comparison of model results.

The results show that production costs will generally increase in all five regions of the U.S (see figure 33). However, the increases vary by region and the variables with the greatest influence do so as well. The low response scenario showed a modest 1-4% increase in production costs. The medium response scenario caused larger increases in production costs, between 4 and 11%. The high response scenario affected farmers the most with a 12-18% increase in production costs. Overall, the results indicate an increase in production costs for all regions no matter the scenario.

F. Limitations of the Model

The model's limitations can be grouped into three broad categories. The first category stems from the fact that averages were used for different regions even though there is great variability within the regions. The second type of limitations comes from uncertainty in the model parameters. The third type of limitations arises from assumptions built into the model. Each type of limitation can be improved upon in different ways.

The five regions cover broad, diverse areas of the United States. While the model used regional averages for input variables such as breakdown of production costs, temperature changes, feed composition, price of feed components, and percentage of feed grown at home, there is large variability within each region. A large dairy farm in California, for example, would have different values than a small dairy farm in Washington, but the model assumes that the variables are the same for both farms. Therefore, according to the model, the impacts of climate change on these two farms are the same, when in reality the effects would be different.

Conducting a regional analysis or allowing farmers to run the model for themselves is a potential solution to these aggregation problems. Farmers know the breakdown of production costs for their farms, the feed composition, and percentage of feed grown. In addition, the farmers could be presented with temperature change tables for their regions. Thus, a farmer could input their data into the model, receiving farm specific results. These results would provide farmers with a more accurate understanding of the effects of climate change than the current regional averages.

Another source of limitations to the model comes from uncertainty in the model parameters including elasticity, changes in crop yields, and changes in fuel and electricity prices. Published research for these parameters is somewhat limited and variable. It was difficult, for example, to find values for elasticity, which has a large impact on the model. In addition, researchers have found various values of changes in crop yields due to climate change. For this reason, multiple scenarios were run to account for this uncertainty. Furthermore, the change in crop yield and fuel and electricity prices is dependent upon the location of a dairy farm. As additional research refines these parameters, the model parameters can be changed to improve the accuracy of the results.

The third source of limitations comes from model assumptions. These assumptions were made to simplify the model, but should be expanded upon in the future. For example, the model treated the crop and its silage as the same, even though climate change will impact the crop and the plant differently. If yield changes were identified for silage, this could be entered into the model. In addition, the price of crops was derived from the elasticity of supply. The model does not consider the elasticity of land or other factors such as biofuels that would affect the price of crops.

Furthermore, some effects were not included in the model such as adaptation strategies or substitution of feed components. These factors could greatly impact the change in production costs. Farmers are resilient and responsive to changes on the farm. Farmers could grow new varieties of crops that are more adapted to changes in climate. In addition, farmers could select cows that have improved heat tolerance. Farmers could also implement strategies to reduce the effect of heat stress such as fans and misters. These are only a few of the possible adaptation strategies farmers could employ, which would reduce the change in production costs.

The composition of feed fed to dairy cows varies. It changes depending upon the price and availability of the feed. If corn, for example, becomes too expensive, farmers may reduce the amount of corn fed to their cows for another feed source. This change would impact the milk yield because the amount of roughage in a cow's diet affects the milk yield. The model does not account for these feed substitutions, which would affect the change in feed costs and milk yield. The model could be expanded to include these factors and build in an optimization component that predicts how the feed composition may change due to a change in feed prices.

The model currently conducts every calculation in percent change. Another way to build this model would be to change the equations from percent change to actual changes in costs. While the two methods would achieve the same result, it might be easier to communicate the information if the data was in actual changes instead of percentages.

IV. Conclusion

The model predicts that climate change will significantly increase the production costs to dairy farmers in the future. These results will help farmers gain some insight to future possible scenarios. Since farmers operate with low profit margins, a small increase in production costs can have a great effect on dairy farms economic viability. These results will help farmers plan and prepare themselves for future obstacles they may face. Additionally, farmers can input their own data into the model to receive personalized farm specific results.

While this model shows farmers what may happen to their production costs in the future, it does not provide suggestions to mitigate these impacts. The model could be expanded to incorporate adaptation strategies and optimization routines to identify practices that can help farmers adapt to changes in climate. These additions to the model would provide farmers with the tools and information needed to successfully mitigate the negative effects of a changing climate on their dairy operations.

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Appendix 1:

A1 Family:
"The A1 storyline and scenario family describes a future world of very rapid economic development, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income." (Source: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf)
The A1 family is further subdivided in three groups that describe possible directions of changes in technology to support the energy system.
A1FI – Fossil Fuel Intensive
A1T – Non Fossil Fuel energy source
A1B – Balance across all sources

A2 Family:
"The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines." (Source: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf)

B1 Family:
"The B1 storyline and scenario family describes a convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives." (Source: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf)

B2 Family:
"The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels." (Source: http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf)