Agriculture, Climate Change and Carbon Sequestration

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Carbon sequestration and reductions in greenhouse gas emissions can occur through a variety of agriculture practices. This publication provides an overview of the relationship between agriculture, climate change and carbon sequestration. It also investigates possible options for farmers and ranchers to have a positive impact on the changing climate and presents opportunities for becoming involved in the emerging carbon market.

An organic wheat grass field. Growing research is showing that organic production systems are one of the most climate-friendly systems of food production.

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Introduction

The Earth's average surface temperature increased 1.3 degrees Fahrenheit over the past century, and is projected by the Intergovernmental Panel on Climate Change to increase by an additional 3.2 to 7.2 degrees over the 21st century (IPCC, 2007a). These seemingly slight changes in temperature could have profound implications for farmers and ranchers. According to the Environmental Protection Agency, an increase in average temperature can:

- lengthen the growing season in regions with relatively cool spring and fall seasons;
- adversely affect crops in regions where summer heat already limits production;
- increase soil evaporation rates; and
- increase the chances of severe droughts (2008a).

Innovative farming practices such as conservation tillage, organic production, improved cropping systems, land restoration, land use

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change and irrigation and water management, are ways that farmers can address climate change. Good management practices have multiple benefits that may also enhance profitability, improve farm energy efficiency and boost air and soil quality.

Climate change science

Natural shifts in global temperatures have occurred throughout human history. The 20th century, however, has seen a rapid rise in global temperatures. Scientists attribute the temp increase to a rise in carbon dioxide and other greenhouse gases released from the burning of fossil fuels, deforestation, agriculture and other industrial processes. Scientists refer to this phenomenon as the enhanced greenhouse effect.

The naturally occurring greenhouse effect traps the heat of the sun before it can be released back into space. This allows the Earth's surface to remain warm and habitable. Increased levels of greenhouse gases enhance the naturally occurring greenhouse effect by trapping even more of the sun's heat, resulting in a global warming effect. *Figure 1* illustrates the natural and enhanced greenhouse effects (Pew Center on Global Climate Change, 2008).

The primary greenhouse gases associated with agriculture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Although carbon dioxide is the most prevalent greenhouse gas in the atmosphere, nitrous oxide and methane have longer durations in the atmosphere and absorb more long-wave radiation. Therefore, small quantities of methane and nitrous oxide can have significant effects on climate change.

Several excellent resources and fact sheets explain the greenhouse effect and the science behind climate change. See the **Resources** section for information on how to obtain copies.

Related ATTRA Publications

Conservation Tillage

Pursuing Conservation Tillage Systems for Organic Crop Production

Energy Saving Tips for Irrigators

Anaerobic Digestion of Animal Wastes: Factors to Consider

Biodiesel: The Sustainability Dimensions

Ethanol Opportunities and Questions

Renewable Energy Opportunities on the Farm

Federal Resources for Sustainable Farming and Ranching

Figure 1. The Greenhouse Effect
Source: The National Academy of Sciences. www.climatechange.ca.gov/publications/faqs.html

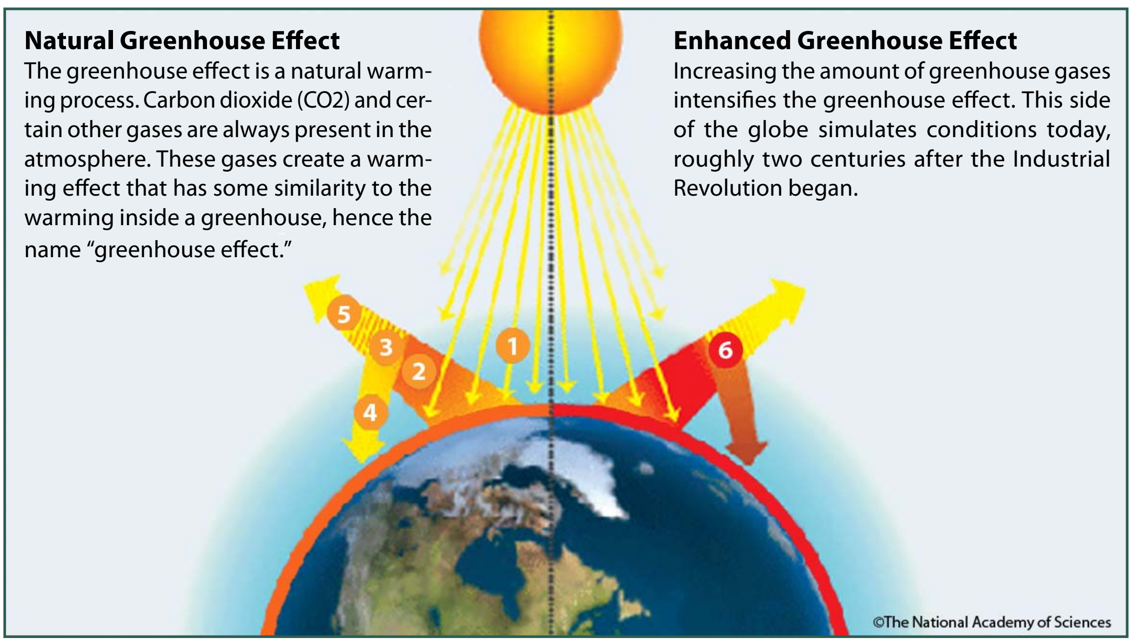


Illustration of the greenhouse effect (courtesy of the Marion Koshland Science Museum of the National Academy of Sciences). Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth **(1)** is absorbed and converted to heat, which warms the surface. The surface **(2)** emits infrared radiation to the atmosphere, where some of it **(3)** is absorbed by greenhouse gases and **(4)** re-emitted toward the surface; some of the heat is not trapped by greenhouse gases and **(5)** escapes into space. Human activities that emit additional greenhouse gases to the atmosphere **(6)** increase the amount of infrared radiation that gets absorbed before escaping into space, thus enhancing the greenhouse effect and amplifying the warming of the earth.

How does climate change influence agriculture?

Climate change may have beneficial as well as detrimental consequences for agriculture. Some research indicates that warmer temperatures lengthen growing seasons and increased carbon dioxide in the air results in higher yields from some crops. A warming climate and decreasing soil moisture can also result in production patterns shifting northward and an increasing need for irrigation. Changes, however, will likely vary significantly by region. Geography will play a large role in how agriculture might benefit from climate change. While projections look favorable for some areas, the potential of increased climate variability and extremes are not necessarily considered. Benefits to agriculture might be offset by an increased likelihood of heat waves, drought, severe thunderstorms and tornadoes. An increase in climate variability makes adaptation difficult for farmers.

The U.S. Department of Agriculture released a report in May 2008 that focused on the effects of climate on agriculture, specifically on cropping systems, pasture and grazing lands and animal management (Backlund et al., 2008). The following findings are excerpted from the report:

- With increased carbon dioxide and higher temperatures, the life cycle of grain and oilseed crops will likely progress more rapidly.
- The marketable yield of many horticultural crops, such as tomatoes, onions and fruits, is very likely to be more sensitive to climate change than grain and oilseed crops.
- Climate change is likely to lead to a northern migration of weeds. Many weeds respond more positively to increasing carbon dioxide than most cash crops.
- Disease pressure on crops and domestic animals will likely increase with earlier springs and warmer winters.
- Projected increases in temperature and a lengthening of the growing season will likely extend forage production into late fall and early spring.
- Climate change-induced shifts in plant species are already under way in rangelands. The establishment of perennial herbaceous species is reducing soil water availability early in the growing season.
- Higher temperatures will very likely reduce livestock production during the summer season, but these losses will be partially offset by warmer temperatures during the winter season (Backlund et al., 2008).

How does agriculture influence climate change?

Agriculture's contribution to greenhouse gas emissions

Agriculture activities serve as both sources and sinks for greenhouse gases. Agriculture sinks of greenhouse gases are reservoirs of carbon that have been removed from the atmosphere through the process of biological carbon sequestration.

The primary sources of greenhouse gases in agriculture are the production of nitrogen-based fertilizers; the combustion of fossil fuels such as coal, gasoline, diesel fuel and natural gas; and waste management. Livestock enteric fermentation, or the fermentation that takes place in the digestive systems of ruminant animals, results in methane emissions.

Carbon dioxide is removed from the atmosphere and converted to organic carbon through the process of photosynthesis. As organic carbon decomposes, it is converted back to carbon dioxide through the process of respiration. Conservation tillage, organic production, cover cropping and crop rotations can drastically increase the amount of carbon stored in soils.

In 2005, agriculture accounted for from 10 to 12 percent of total global human-caused emissions of greenhouse gases, according the Intergovernmental Panel on Climate Change (IPCC, 2007b). In the United States, greenhouse gas emissions

Conservation tillage, organic production, cover cropping and crop rotations can drastically increase the amount of carbon stored in soils.

from agriculture account for 8 percent of all emissions and have increased since 1990 (Congressional Research Service, 2008). *Figure 2* presents recent data in carbon dioxide equivalents (CO_2e). Greenhouse gases have varying global warming potentials, therefore climate scientists use carbon dioxide equivalents to calculate a universal measurement of greenhouse gas emissions.

Figure 2. Greenhouse gas emissions and carbon sinks in agricultural activities, 1990-2005 (CO_2 equivalent).

Source	1990	1995	2000	2005	Avg. 2001-2005
	million metric tons CO_2 equivalent ($MMTCO_2$-Eq)				
U.S. Agricultural Activities					
GHG Emissions (CH_4 and N_2O)					
Agriculture Soil Management[a]	366.9	353.4	376.8	365.1	370.9
Enteric Fermentation[b]	115.7	120.6	113.5	112.1	115.0
Manure management	39.5	44.1	48.3	50.8	45.6
Rice Cultivation	7.1	7.6	7.5	6.9	7.4
Agricultural Residue Burning	1.1	1.1	1.3	1.4	1.2
Subtotal	530.3	526.8	547.4	536.3	540.1
Carbon Sinks					
Agricultural Soils	(33.9)	(30.1)	(29.3)	(32.4)	(31.7)
Other	na	na	na	na	na
Subtotal	(33.9)	(30.1)	(29.3)	(32.4)	(31.7)
Net Emissions, Agriculture	496.4	496.7	518.1	503.9	508.4
Attributable CO_2 emissions:[c] Fossil fuel/mobile combustion	46.8	57.3	50.9	45.5	52.6
% All Emissions, Agriculture[d]	8.5%	8.0%	7.7%	7.4%	8.0%
% Total Sinks, Agriculture	4.8%	3.6%	3.9%	3.9%	4.0%
% Total Emissions, Forestry	0.2%	0.2%	0.2%	0.3%	0.3%
% Total Sinks, Forestry[e]	94.3%	92.0%	94.8%	94.7%	95.0%
Total GHG Emissions, All Sectors	6,242.0	6,571.0	7,147.2	7,260.4	6,787.1
Total Carbon SInks, All Sectors	(712.8)	(828.8)	(756.7)	(828.5)	(801.0)
Net Emissions, All Sectors	5,529.2	5,742.2	6,390.5	6,431.9	5,986.1

Source: EPA, Inventory of U.S. Grenhouse Gas Emissions and Sinks: 1990-2005, April 2007, *[http://epa.gov/climatechange/emissions/usinventoryreport.html]*. Table ES-2, Table 2-13, Table 6-1, Table 7-1, and Table 7-3. EPA data are reported i teragrams (tg.), which are equivalent to one million metric tons each.

a. N_2O emissions from soil management and nutrient/chemical applications on croplands.
b. CH_4 emissions from ruminant livestock.
c. Emissions from fossil fuel/mobile combustion associated with energy use in the U.S. agriculture sector (excluded from EPA's reported GHG emissions for agricultural activities).
d. Does not include attributable CO_2 emissions from fossil fuel/mobile combustion.
e. Change in forest stocks and carbon uptake from urban trees and landfilled yard trimmings.

Figure 3. Agricultural greenhouse gas emissions, average from 2001 to 2005. *Source: EPA, 2007 Inventory report, April 2007. www.epa.gov/climatechange/emissions/usinventoryreport.html*

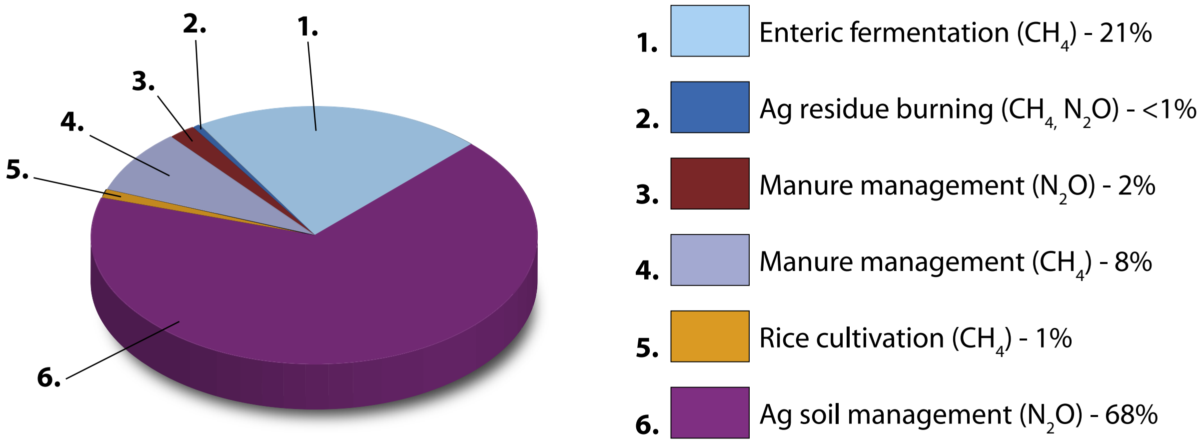


Figure 3 illustrates agricultural greenhouse gas emissions by source in the United States.

The following is evident from the information in *Figures 2 and 3:*

- Despite some improvement in certain areas since 1990, the U.S. agricultural production sector increased its greenhouse gas emissions and expanded its role in climate change.
- The U.S. agricultural production sector is a net emitter of greenhouse gas emissions. That is, agricultural production annually creates more greenhouse gas emissions than it captures, despite the potential for the sector to sequester higher levels of carbon with management changes.
- The U.S. agricultural production sector contributes more greenhouse gas emissions from methane (CH_4) and nitrous oxide (N_2O) than from carbon dioxide (CO_2).
- Agricultural soil management is the single greatest contributor to greenhouse gas emissions from the U.S agricultural production sector. Enteric fermentation (flatulence and belches of ruminants) and manure management are also large contributors.

Carbon sequestration

Carbon sequestration in the agriculture sector refers to the capacity of agriculture lands and forests to remove carbon dioxide from the atmosphere. Carbon dioxide is absorbed by trees, plants and crops through photosynthesis and stored as carbon in biomass in tree trunks, branches, foliage and roots and soils (EPA, 2008b). Forests and stable grasslands are referred to as carbon sinks because they can store large amounts of carbon in their vegetation and root systems for long periods of time. Soils are the largest terrestrial sink for carbon on the planet. The ability of agriculture lands to store or sequester carbon depends on several factors, including climate, soil type, type of crop or vegetation cover and management practices.

The amount of carbon stored in soil organic matter is influenced by the addition of carbon from dead plant material and carbon losses from respiration, the decomposition process and both natural and human disturbance of the soil. By employing farming practices that involve minimal disturbance of the soil and encourage carbon sequestration, farmers may be able to slow or even reverse the loss of carbon from their fields. In the United States, forest and croplands currently sequester the equivalent of 12 percent of U.S. carbon dioxide emissions from the energy, transportation and industrial sectors (EPA, 2008b).

Figure 4. Carbon pools in forestry and agriculture. *Source: EPA. www.epa.gov/sequestration/local_scale.html*

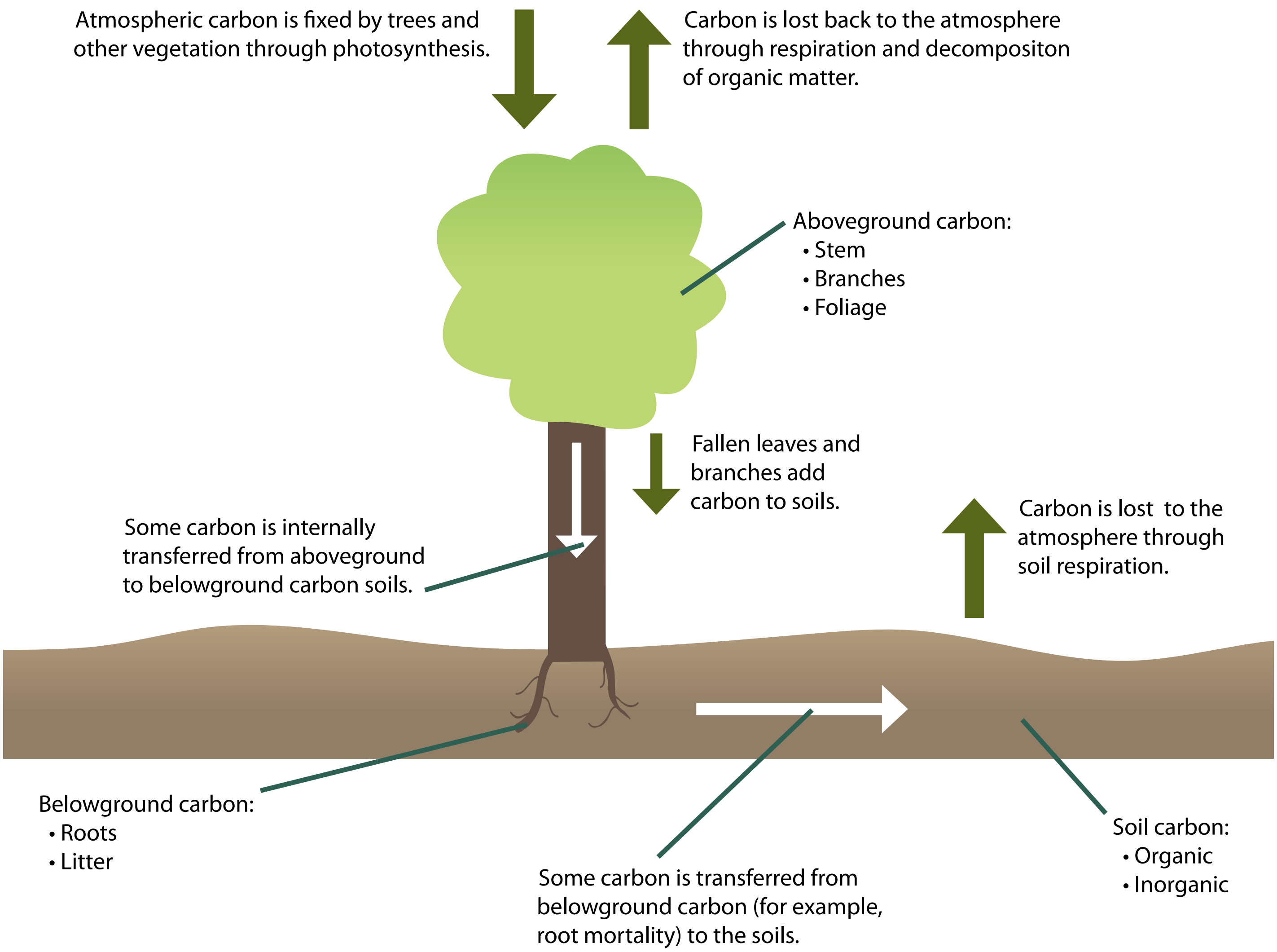


Figure 4, adapted from the EPA, illustrates the different processes through which trees and soils can gain and lose carbon.

Agriculture's role in mitigating climate change

Several farming practices and technologies can reduce greenhouse gas emissions and prevent climate change by enhancing carbon storage in soils; preserving existing soil carbon; and reducing carbon dioxide, methane and nitrous oxide emissions.

Conservation tillage and cover crops

Conservation tillage refers to a number of strategies and techniques for establishing crops in the residue of previous crops, which are purposely left on the soil surface. Reducing tillage reduces soil disturbance and helps mitigate the release of soil carbon into the atmosphere. Conservation tillage also improves the carbon sequestration capacity of the soil. Additional benefits of conservation tillage include improved water conservation, reduced soil erosion, reduced fuel consumption, reduced compaction, increased planting and harvesting flexibility, reduced labor requirements and improved soil tilth. For further information, see the ATTRA publication *Conservation Tillage*.

Improved cropping and organic systems

Recent reports have investigated the potential of organic agriculture to reduce greenhouse gas emissions (Rodale Institute, 2008). Organic systems of production increase soil organic matter levels through the use of composted animal manures and cover crops. Organic cropping systems also eliminate the emissions from the production and transportation of synthetic fertilizers. Components of organic agriculture could be implemented with other sustainable farming systems, such as conservation tillage, to further increase climate change mitigation potential. See the ATTRA publication *Pursuing Conservation Tillage Systems for Organic Crop Production* for more information.

Generally, conservation farming practices that conserve moisture, improve yield potential and reduce erosion and fuel costs also increase soil carbon. Examples of practices that reduce carbon dioxide emissions and increase soil carbon include direct seeding, field windbreaks, rotational grazing, perennial forage crops, reduced summer fallow and proper straw management (Alberta Agriculture and Rural Development, 2000). Using higher-yielding crops or varieties and maximizing yield potential can also increase soil carbon.

Land restoration and land use changes

Land restoration and land use changes that encourage the conservation and improvement of soil, water and air quality typically reduce greenhouse gas emissions. Modifications to grazing practices, such as implementing sustainable stocking rates, rotational grazing and seasonal use of rangeland, can lead to greenhouse gas reductions. Converting marginal cropland to trees or grass maximizes carbon storage on land that is less suitable for crops.

Irrigation and water management

Improvements in water use efficiency, through measures such as irrigation system mechanical improvements coupled with a reduction in operating hours; drip irrigation technologies; and center-pivot irrigation systems, can significantly reduce the amount of water and nitrogen applied to the cropping system. This reduces greenhouse emissions of nitrous oxide and water withdrawals. For more information, see the ATTRA publication *Energy Saving Tips for Irrigators*.

Nitrogen use efficiency

Improving fertilizer efficiency through practices like precision farming using GPS tracking can reduce nitrous oxide emissions. Other strategies include the use of cover crops and manures (both green and animal); nitrogen-fixing crop rotations; composting and compost teas; and integrated pest management. The ATTRA Farm Energy Web site contains information about reducing nitrogen fertilizer on the farm at the following link: *www.attra.ncat.org/farm_energy/nitrogen.html*.

Conservation farming practices that conserve moisture, improve yield potential and reduce erosion and fuel costs also increase soil carbon.

Methane capture

Large emissions of methane and nitrous oxide are attributable to livestock waste treatment, especially in dairies. Agriculture methane collection and combustion systems include covered lagoons and complete mix and plug flow digesters. Anaerobic digestion converts animal waste to energy by capturing methane and preventing it from being released into the atmosphere. The captured methane can be used to fuel a variety of on-farm applications, as well as to generate electricity. Additional benefits include reducing odors from livestock manure and reducing labor costs associated with manure removal. For more information on anaerobic digestion, see the ATTRA publication *Anaerobic Digestion of Animal Wastes: Factors to Consider*.

Biofuels

There is significant scientific controversy regarding whether biofuels — particularly those derived from oilseeds (biodiesel), feed corn (ethanol) or even from cellulosic sources — are carbon neutral. To ascertain the true climate neutrality of biofuels requires a careful life-cycle analysis of the specific biofuel under consideration. Also, an analysis is needed to understand what the global land use change implications will be if farmers grow more of a specific biofuel feedstock. For further information on biofuels, see the ATTRA publications *Biodiesel: The Sustainability Dimensions* and *Ethanol Opportunities and Questions.*

Other renewable energy options

Renewable energy opportunities such as wind and solar also present significant opportunities for the agriculture sector to reduce greenhouse gas emissions. For further information about these options, see the ATTRA publication *Renewable Energy Opportunities on the Farm.*

"Creating farm and forestry systems with strong incentives for growing soil carbon could well be at the center of climate stabilization." (Mazza, 2007)

The value of soil carbon: Potential benefits for agriculture

As Mazza (2007) has remarked, "creating farm and forestry systems with strong incentives for growing soil carbon could well be at the center of climate stabilization."

Thus, a new crop that farmers and ranchers may grow in the future is carbon. The Natural Resources Conservation Service, part of the USDA, has long been a promoter of managing carbon in efforts to improve soil quality.

As with any crop, farmers and ranchers need a market for this new crop, as well as a price that will make it more profitable to grow. From a broader social context, the questions of who will purchase this new crop and what is a fair price are also of private and public importance. Voluntary private carbon markets exist in the United States. Federal government markets are expected to be created soon. How to value carbon from the perspective of the individual farmer and rancher, as well as society at large, is the heart of understanding the role agriculture can play in carbon sequestration and climate stabilization.

The two most frequently discussed systems to create value for offsetting greenhouse gas emissions are known as *carbon taxation* and *cap and trade*. Government subsidies are discussed less often, but will also play a role in greenhouse gas emission reductions.

Charge systems: Carbon tax

By taxing every ton of carbon in fossil fuels or every ton of greenhouse gas companies emit, entities that emit greenhouse gases or use carbon-based fuels will have an incentive to switch to alternative renewable fuels, invest in technology changes to use carbon-based fuels more efficiently and in general adopt practices that would lower their level of greenhouse gas emissions. Thus a carbon or greenhouse gas emission tax values carbon in negative terms of tax avoidance. Those farms and ranches that emit or use less carbon-intensive fuels pay a smaller tax.

From the perspective of farmers and ranchers, a carbon tax would increase the direct and indirect costs of agricultural production. Farmers and ranchers use carbon-based fuels directly in the forms of petroleum and natural gas and indirectly in the forms of carbon-based fertilizers and pesticides and fuel-intensive inputs. Thus, a carbon tax could move farmers and ranchers to shift to systems of production that either eliminate the use of fossil fuels and inputs or at least improve the efficiency of their use.

However, proponents of carbon taxes have generally sought to exclude the agriculture sector from such taxation. For the most part, carbon tax proponents have been more interested in placing greenhouse gas emission taxes on upstream producers of the original source products. This includes coal, petroleum and natural gas producers and major emitters such as large electric utilities. Nonetheless, as people work to reduce greenhouse gas emissions, the potential to place a carbon tax on sectors like agriculture may become more likely.

Benefits of a carbon tax for farmers and ranchers

A major benefit of a carbon or greenhouse gas emission tax would be the creation of a stream of tax revenue that the government could use to further induce the practice and technology changes necessary to lower greenhouse gas emissions. For example, many of the current agriculture conservation programs, such as the Environmental Quality Incentive Program and the newer Conservation Stewardship Program, support improvements in soil quality and could be funded in part from emission or carbon taxes, thereby providing a revenue source to subsidize those who adopt or maintain emission-reduction practices or carbon sequestration activities. See the ATTRA publication *Federal Resources for Sustainable Farming and Ranching* for more information. Tax revenues could also assist in the support of conservation programs like the Conservation Reserve Program, which works to keep sensitive and highly erodible lands out of production since these lands sequester soil carbon.

Another benefit of this approach is that a tax provides a clear and stable cost to current practices. A tax also makes it easier to determine changes that will be more profitable in a new cost environment. For instance, if a concentrated animal feeding operation understood the cost of their emissions as expressed by their emission tax, it would be easier for the operation to determine alternatives to current practices that would be cost efficient. At a high enough tax rate, installing methane digesters to lower greenhouse gas emission would become economically feasible.

Finally, it has been argued that a carbon tax approach is cost effective in implementation, at least when compared to the cap-and-trade method of achieving greenhouse gas emissions reductions. As recent Congressional Budget Office report states: "available research suggests that in the near term, the net benefits (benefits minus costs) of a tax could be roughly five times greater than the net benefits of an inflexible cap" (Congressional Budget Office, 2008).

Downside of a carbon tax

The introduction of any tax results in discussions of where the burden of taxation lies and issues of equity. In short, taxation is about who pays and who does not. New taxes also often result in a public discussion of the fairness of the tax. There is logic to the argument that the burden of a carbon or greenhouse gas emission tax should be placed first and foremost on those who either create carbon-intensive fuels or those who are the largest emitters of greenhouse gases. The greatest source of greenhouse gas emissions in the United States is the combustion of fossil fuels. Since agriculture uses a small percentage of U.S. fossil fuels, an argument can be made that the burden of taxation should not to fall on this sector. Still, agriculture is heavily dependent on fossil fuels and any carbon or greenhouse gas emission tax would likely be costly.

A tax provides a clear and stable cost to current practices.

The ability of any individual farmer or rancher to pass on the increased costs of fossil fuels that this kind of taxation would create is much more limited than in other sectors of the economy. For instance, if a carbon tax is placed on diesel fuel, diesel fuel manufacturers can more easily pass on the tax burden to the consumers of the diesel. The ability to pass on costs to consumers is greater in industries where there is little product substitution and where a few producers dominate the market. This is not the case for farmers and ranchers, given their relative lack of market concentration and power.

Cap and trade: A private market for greenhouse gas emissions

A government-sponsored cap-and-trade system would create a new market for greenhouse gas emissions by creating a new property right — the right to emit.

The market is created by a government that sets a limit or cap on total greenhouse gas emissions allowed. Companies that emit greenhouse gases are issued emission permits that allow a certain amount of emissions. Companies and groups that exceed their allowed emissions must purchase offsets from other entities that pollute less than their allowance or from entities that sequester carbon.

These exchangeable emission permits, often called allowances, are measured in tons of carbon dioxide equivalents per year. Carbon dioxide equivalents provide a common measure for all greenhouse gas emissions and are calculated by converting greenhouse gases into carbon dioxide equivalents according to their global warming potential.

Over time, the government will continually lower the total level of allowances to meet an established level of acceptable total emissions. As the supply of allowances decreases, the value of the allowances will rise or fall depending on demand and on the ability of emitters to make necessary changes to reduce emissions or purchase offsets from groups more capable of reducing emissions.

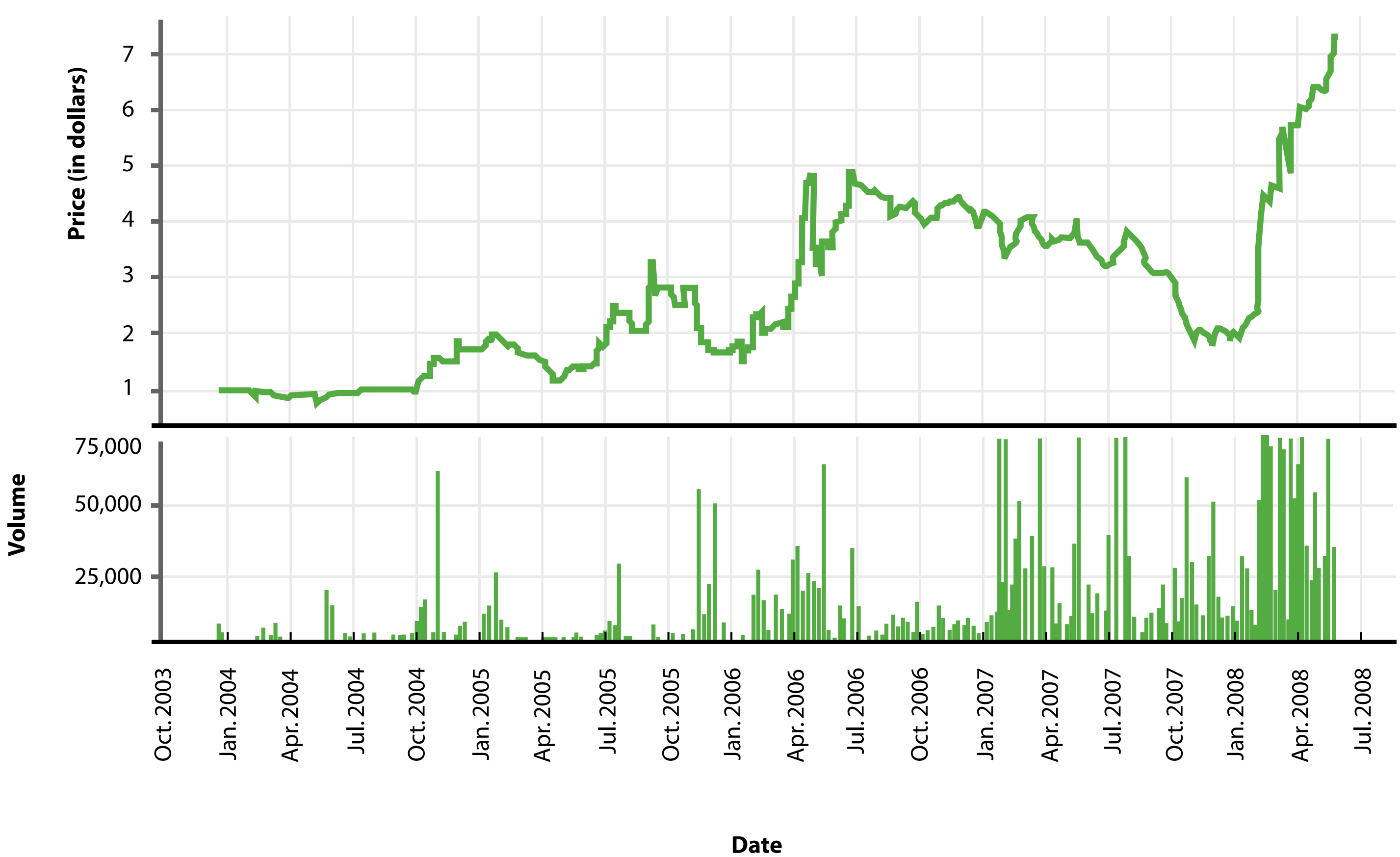
Benefits for farmers and ranchers

Depending on the practices adopted, farmers and ranchers could be a source of inexpensive carbon reduction and capture the value of these allowances as offsets. In short, the value of offsets would become the market price of carbon equivalents. This would become the value of the new crop — carbon — that farmers and ranchers could grow.

From the May 26, 2008 issue of *High Country News:*

> For example, if a farmer shifted to an organic system of production, measurable improvements in the ability of the farmer to sequester carbon could be verified and the farmer could sell this sequestered carbon at the current carbon market price set in the new emissions market (Ogburn, 2008).

Figure 5. Chicago Climate Exchange daily report. ***Source: Chicago Climate Exchange. www.chicagoclimateexchange.com***



A limited, privately created and voluntary cap-and-trade system called the Chicago Climate Exchange (CCX) has been in operation in the United States since 2003. The emission cap is set by emitting entities that voluntarily sought to limit greenhouse gas emissions. Purchases of agriculture offsets have been part of this exchange. As can be seen from *Figure 5*, the price of carbon dioxide equivalents per ton has varied significantly over the life of the exchange and hit its highest level in 2008 at $7.35 per ton. This price has not yet resulted in an overwhelming participation by farmers and ranchers.

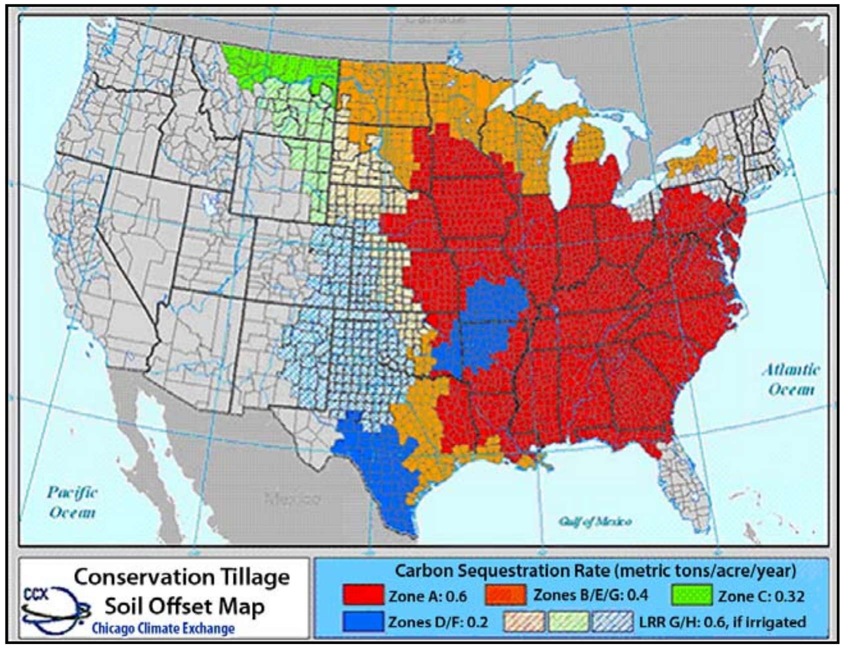
Downsides of cap and trade

For farmers and ranchers to provide carbon offsets for greenhouse gas emitters, farmers and ranchers must be willing to make long-term, or even permanent, changes in not only practices but perhaps whole systems of production. These changes also need to provide verifiable changes that result in true offsets of greenhouse gas emissions. The issues of verifiability, permanence and what is known as *additionality* are critical to the success of agriculture's role in the cap-and-trade system and the ultimate reduction of greenhouse gas emissions.

Verifiability is critical because the system or practice change must result in a measurable change in the amount of carbon stored. For example, the adoption of a no-till cultivation practice is thought to result in soil with higher carbon sequestration capacity. However, there is continuing scientific debate over whether the practice of continuous no-till does in fact lead to long-term additional storage of carbon in the soil (Baker et al., 2007).

The CCX divided the United States into zones and allocated specific levels of carbon sequestration to each acre farmed in a particular zone under continuous no-till practices, as illustrated in *Figure 6*.

Figure 6. Conservation tillage soil offset map. ***Source: Chicago Climate Exchange.*** **www.chicagoclimateexchange.com**



While there may be some need to simplify the implementation of a nationwide soil carbon sequestration project related to tillage practice change, it is very doubtful that the actual carbon storage levels allocated can be achieved across areas that are so large. Finally, the CCX does not verify the actual carbon storage as a result of the practice change, but only monitors that the practice is maintained during the life of the contract. Thus, it is doubtful the carbon offset truly matches actual carbon sequestered.

The issue of permanence is also critical. What happens after a farmer or rancher changes to a practice or system of production, is paid for carbon stored and then decides to change practices and potentially release the carbon that he or she was paid to sequester to offset emissions?

Additionality refers to the issue that a farmer or rancher can only offer and be paid for an offset for a new sequestration of carbon, not for a practice or a system of production already in place. For instance, if a rancher developed a permanent wind shelter belt, that change in land use would likely result in new, or additional, carbon sequestration. However, a rancher who already developed a similar shelter belt would not be eligible for an offset because the rancher would not be providing additional carbon sequestration. Likewise, a farmer already engaged in conservation tillage would not provide additional carbon storage by maintaining that practice. However, the current USDA Conservation Stewardship Program provides a possible payment structure that pays farmers to maintain practices.

Additionality is also important because of the possibility that perverse incentives may be created that encourage farmers or ranchers to release carbon so that they can get paid to store it. For example, a farmer practicing no-till farming may decide to abandon the practice because of the new availability of per-acre payments and switch back to no-till at a later time. To address this and stop additional greenhouse gas emissions, the idea of offsets would need to be expanded to include farmers and ranchers already undertaking a practice or specific land use that stores soil carbon.

Subsidizing positive behavior

A final mechanism that could expand the ability of the agriculture sector to mitigate greenhouse gas emissions is one that is already well known — a direct subsidy. Many federal conservation programs provide incentives, known as cost shares, that help farmers and ranchers make changes in practices to conserve natural resources. For more information, see the ATTRA publication *Federal Resources for Sustainable Farming and Ranching.* For example, data in *Figure 7*, adapted from a Natural Resources Conservation Service bulletin, indicates various crop and animal management practices that can either lower greenhouse gas emissions or increase carbon sequestration. Under the Conservation Stewardship Program and the Environmental Quality Incentive Program, farmers and ranchers can receive incentives to adopt new practices or receive support to maintain such practices. Though not designed to address climate change issues specifically, many federal conservation programs already provide public incentives to reduce greenhouse gas emissions.

Figure 7. Agricultural practices and benefits. ***Source: NRCS. http://soils.usda.gov/survey/global_climate_change.html***

Conservation Practice	GHG Objectives	Additional Benefits
CROPS		
Conservation tillage and reduced field pass intensity	Sequestration, emission reduction	Improves soil, water and air quality. Reduces soil erosion and fuel use
Efficient nutrient management	Sequestration, emission reduction	Improves water quality. Saves expenses, time and labor.
Crop diversity through rotations and cover crops	Sequestration	Reduces erosion and water requirements. Improves soil and water quality.
ANIMALS		
Manure management	Emission reduction	On-farm sources of biogas fuel and possibly electricity for large operations, provides nutrients for crops.
Rotational grazing and improved forage	Sequestration, emission reduction	Reduces water requirements. Helps withstand drought. Increases long-term grassland productivity.
Feed management	Emission reduction	Reduces quantity of nutrients. Improves water quality. More efficient use of feed.

In the future, conservation programs could be refocused to lower greenhouse emissions or increase carbon sequestration. Perhaps modifications of the Conservation Stewardship Program and the Environmental Quality Incentive Program could allow for longer contracts (currently a maximum of five years) so that outcomes are reached and maintained. Also, the programs could add specific validation procedures to assure climate targets are met and sustained.

Benefits of subsidies

There is an immediate benefit to farmers and ranchers willing to make changes that meet the challenges of climate stabilization. If sufficiently funded with outreach and technical assistance, efforts can be made to assure that all farmers and ranchers — regardless of their situation — take advantage of these programs. Finally, resources can be prioritized to different regions of the country or to specific practices or systems of production so programs can be cost-effective in reaching climate change goals.

Downside of subsidies

Subsidies are a public cost, and this is a considerable downside. Furthermore, subsidies are based on the idea that the government can know and assure that the practices it pays for achieve the intended outcomes. For example, the federal government provides significant subsidization of corn ethanol production. Many argue that this changed the price of field corn and increased costs for people who use corn as animal feed and for other countries that import corn to feed people. There are also questions about how subsidies can reduce greenhouse gas emissions. Will subsidizing a shift to a continuous no-till cultivation operation result in greater carbon sequestration? If the scientific understanding of the relationship between carbon sequestration and no-till is simply in error, then public dollars spent to change farmer behavior would be wasted. Furthermore, will subsidization offer the least expensive way to achieve a specific outcome?

Paustian et al. (2006) estimated that it would take a price of at least $13 per ton of carbon dioxide equivalent ($50 per ton of carbon) per year to offset 70 million metric tons (MMT) of carbon dioxide equivalents. This would be a total public cost of close to $1 billion dollars per year for perhaps as long as 40 years. Also, this represents an offset of only 4 percent of total U.S. greenhouse gas emissions in 2004. Is this the least expensive way to reduce greenhouse gas emissions compared to alternative public expenditures? For instance, what if public dollars were committed to a research program to improve the gas mileage of automobiles?

Finally, how do we know that Paustian et. al. are correct in their estimation of the incentive needed to change farming and ranching practices? Recently, Sperow (2007) estimated an average cost to sequester carbon at $261 per ton of carbon. This is considerably higher than the Paustian estimate. While the difference between these studies can be explained by the fact that there is a wide regional variation in carbon sequestration capacity and how sequestration is accomplished, public costs would nonetheless be significant to achieve greenhouse gas emission reductions through subsidization.

The public sector will play an important role in determining how to engage the agriculture sector in the reduction of greenhouse gas emissions.

Summary

The public sector will play an important role in determining how to engage the agriculture sector in the reduction of greenhouse gas emissions. The government can use its power to tax, subsidize or create a new market mechanism to do this. In 2008, the U.S. Senate debated climate change legislation, including the Lieberman-Warner bill. This bill proposes a modified cap-and-trade system with the expectation that the agriculture sector will provide at least 15 percent of the offsets needed to reduce greenhouse gas emissions 71 percent from 2005 levels by 2050. Whether this or future legislation will become the base of future climate change improvements, there is little doubt that agriculture will play some role in the effort.

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Resources

Web sites

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Environmental Protection Agency Global Warming Impacts on Agriculture, *http://epa.gov/climatechange/effects/agriculture.html*

Pew Center on Global Climate Change, *www.pewclimate.org*

Consortium for Agricultural Soil Mitigation of Greenhouse Gases (CASMGS), *www.casmgs.colostate.edu*

Climate Friendly Farming, Washington State University Center for Sustaining Agriculture and Natural Resources, *http://cff.wsu.edu*

Pacific Northwest STEEP - Solutions to Environmental and Economic Problems, *http://pnwsteep.wsu.edu*

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Appendix

How to get involved in voluntary private carbon markets

The future of the voluntary carbon market remains to be seen. Currently, farmer payments from carbon offsets alone are not substantial enough to rationalize decisions for land management changes. However, it is important that the farm sector be included in solutions for mitigating climate change. Before enrolling in any type of carbon credit program, however, it is important to understand eligibility requirements, contract expectations and verification policies. Review all of these items with carbon aggregators before deciding to enroll.

Eligibility

The following table was developed by the National Farmers Union Carbon Credit Program to help farmers determine eligibility for enrollment in specific projects (Farmers Union, 2008). Different aggregators might have different requirements for eligibility, enrollment and contracts.

Eligible land and credit-earning potential

No-till: Carbon credits are issued at the rate of 0.2 to 0.6 metric tons of carbon per acre annually to participants who commit to continuous conservation tillage on enrolled land for at least five future years. In most cases, credit can be earned for the previous year. Enrolled acres may be planted in low-residue crops, such as beans, peas and lentils, no more than three of the contract years. Alfalfa or other hayed forage will be considered as no-till for these contracts.

Seeded grass stands: Carbon credits are earned at a rate of 0.4 metric tons to 1 metric ton per acre annually, even if enrolled in Conservation Reserve Program. Grass stands seeded prior to January 1, 1999, are not eligible for enrollment in the program. Credits can be earned back to 2003 with proper documentation.

Native rangeland: Grassland with a formal grazing plan may earn up to 0.52 tons per acre annually. Credits can be earned back to 2003 with proper documentation.

Forestry: Trees planted after 1990 can earn carbon credits annually, provided no harvest is intended.

Methane offset: Methane captured or destroyed can earn carbon credit. Animal waste systems, including anaerobic digesters and covered lagoons, can be enrolled. Each ton of methane captured earns 21 tons of carbon credits (Farmers Union, 2008).

Finding an aggregator

Several aggregators are located across the country to help farmers and ranchers enroll in carbon offset projects. The following aggregators provide Web sites with detailed information on contracts and enrollment. For a full list of carbon aggregators for the Chicago Climate Exchange, visit their Web site at *www.chicagoclimatex.com.*

- National Farmers Union Carbon Credit Program, *http://carboncredit.ndfu.org*
- National Carbon Offset Coalition, *www.ncoc.us*
- Pacific Northwest Direct Seed Association, *www.directseed.org/carbontrading.html*

How to enroll

You will need to provide the following information to enroll in carbon sequestration programs:

- Land maps to document ownership of a given tract of land, including the legal description of the tract.
- Document of management practices, such as program forms for croplands, grass and forest management.
- A signed contract between the landowner and the Chicago Climate Exchange or an aggregator for the appropriate management practices (Agricultural and Food Policy Center, 2008).

Contracts

Contracts are based on a five-year period for crop production and rangeland projects. At the end of the contract, producers are free to renew the contract for another five years or let the contract expire. Once a contract expires, landowners have no more obligations to the CCX or to the aggregator. However, if a landowner discontinues the approved sequestration production practice prior to the end of the contract, the CCX or aggregator will ask the owner to return the amount of carbon that would have been sequestered up to that point or pay for the same amount of carbon at market price. Additionally, the project owner will not be allowed to further participate in the CCX (Agricultural and Food Policy Center, 2008).

Verification

Once a project is approved, the aggregator is responsible for obtaining independent verification by an approved verifier to ensure the actual greenhouse gas sequestration. A project is subject to initial and annual verification for the duration of its contract with the Chicago Climate Exchange (Chicago Climate Exchange, 2009).

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