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Measuring and Monitoring Carbon in the Agricultural and Forestry Sectors

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Summary

Proposals to reduce emissions of carbon dioxide and other greenhouse gases often include the use of forestry and agricultural practices and lands for carbon sequestration. However, uncertainty about the accuracy of measuring carbon from these activities has led some to question this potential. Basic approaches for measuring forest and agricultural carbon include on-site measurement; indirect measurement from off-site tools; and estimation using models or inferences. Because of challenges associated with balancing the cost and accuracy of these measurement tools, any practicable system for measuring forest and agricultural carbon might require a mix of these approaches.

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Concerns about global climate change and its impacts on the environment and the economy are encouraging policy-makers and stakeholders to explore a range of options to reduce emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs).[1] Congress is considering legislation that would, among other things, provide incentives for parties to reduce or mitigate GHG emissions or to sequester (store) additional CO_2.[2] The possible use of forestry and agricultural practices and lands to mitigate or sequester CO_2 is part of the debate. However, substantial uncertainty exists about current ability to accurately quantify, monitor, and verify the amount of carbon sequestered by various agricultural and forestry practices. By comparison, measuring the carbon from a discrete point source, such as a power plant, is relatively easy and precise. Incorporating the agriculture and forestry sectors in an emissions reduction program will likely require a firm basis for measuring carbon inventories and change for forestry and agricultural practices and lands.

Purpose of Measuring Forest and Agricultural Carbon

Farm and forest activities can be both a source and a sink of GHGs, releasing GHGs through plant and animal respiration and decomposition and removing CO_2 through photosynthesis, storing it in vegetation and soils (a process known as sequestration). A range of land management, agricultural conservation, and other farmland practices can reduce or abate emissions and/or sequester carbon. These include tree planting, soil conservation, manure and grazing management, and land retirement, conversion, and restoration.[3] Many of these activities, however, may be impracticable for an emission trading program because they might not meet credible standards for quantifying, monitoring, and verifying emission reduction or carbon storage.

Reliable tools and techniques are needed for carbon inventories and carbon change on forests and agricultural lands. The ability to measure carbon levels allows countries that have committed to reducing GHG emissions to measure their current annual emissions and carbon storage (and changes in carbon stocks).[4] Current estimates show that forests account for a significant share of estimated existing carbon stocks globally; agricultural lands account for a small share of stored carbon. Also, the ability to measure carbon levels provides the means to estimate the mitigation potential of forest or agriculture activities that sequester additional carbon in soils or vegetation (i.e., result in a net reduction compared to estimated baseline conditions or current sequestration).

[1] Under the United Nations Framework Convention on Climate Change (UNFCC), GHGs include CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Because various GHGs have different climatic consequences, they are typically converted to a standard measure, usually metric tons of CO_2-equivalents (CO_2-Eq.).

[2] CRS Report RL33846, *Greenhouse Gas Reduction: Cap-and-Trade Bills in the 110th Congress*, by Larry Parker, Brent D. Yacobucci, and Jonathan L. Ramseur.

[3] See CRS Report RL33898, *Climate Change: The Role of the U.S. Agriculture Sector and Congressional Action*, by Renée Johnson.

[4] The official U.S. estimates of current national GHG emissions and carbon uptake, including agriculture and forestry estimates, are those published by the U.S. Environmental Protection Agency (EPA) in its annual *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.

This may allow a farm or forestry activity to be recognized as a way to mitigate or *offset*[5] emissions—through voluntary action, an emissions trading market, or a regulatory program.

For an emissions trading program to be credible, a participating entity is usually required to meet a series of established protocols that specify what, when, where, and how to measure changes in carbon. Protocols provide technical guidelines or standardized rules for quantifying, monitoring, and verifying the mitigation of an activity. They specify requirements on project eligibility, scale and baseline measurements, measurement frequency, and verification. The difficulty is developing credible protocols that are quantitatively defensible and readily applicable across areas with differing land uses, weather, and other site-specific conditions. Protocols also address, to varying degrees, concerns about the validity of activities, such as additionality, leakage, and permanence.[6]

Protocols may be either voluntary or set by regulation. In one voluntary market, the Chicago Climate Exchange (CCX) has protocols for a range of soil and land management projects, including agricultural methane, soil carbon, rangeland soil carbon management, and tree planting projects.[7] The Regional Greenhouse Gas Initiative (RGGI)—the first regional mandatory, market-based effort to reduce GHG emissions—is developing technical standards for a narrower set of offset projects from the agricultural and forestry sectors, providing for afforestation and methane reduction from livestock operations.[8] Individual requirements of current protocols and standards can vary widely by program.

Decisions Needed in Setting Measurement Requirements

Numerous methods exist to measure forest and agricultural carbon. The appropriate measure to use in specific circumstances depends on several variables, including the purpose for measuring the carbon, the scale and basis to be measured, the frequency of the measurement, and how the measurement is to be verified.

Scale and Baseline

Two geographic scales are commonly used for measuring GHG emissions—the national/regional level to report GHG emissions and participate in broad efforts to reduce emissions; and the local/site-specific level for projects to offset emissions. Regardless of scale, the emission reduction or carbon sequestration is compared to a *baseline*—the historic GHG emissions or

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[5] In this report, *offset* refers to any action that reduces or mitigates GHG emissions, usually from an unrelated source (e.g., increased carbon storage on forest or farmlands to offset emissions from automobiles). The term *offsets* may also be used to refer to approved carbon reduction or sequestration projects under specific regulatory or voluntary GHG reduction programs. See CRS Report RL34560, *Forest Carbon Markets: Potential and Drawbacks*, by Ross W. Gorte and Jonathan L. Ramseur.

[6] See CRS Report RL34436, *The Role of Offsets in a Greenhouse Gas Emissions Cap-and-Trade Program: Potential Benefits and Concerns*, by Jonathan L. Ramseur, *Sourcebook for Land Use, Land-Use Change, and Forestry Projects*, Winrock International, 2005.

[7] CCX, "CCX Offsets Program," at http://www.chicagoclimatex.com/content.jsf?id=23.

[8] RGGI, *Regional Greenhouse Gas Initiative Model Rule*, 1/5/07 Final, at http://rggi.org/docs/model_rule_corrected_1_5_07.pdf.

carbon stocks at a specified point in time. The scale and baseline timing are typically specified in the protocol of the reporting, marketing, or regulating organization. Sometimes, for projects with multiple land uses, the land is stratified into the various land uses (e.g., cropland, pasture, sapling forest, mature forest), with a different baseline established for each use.[9]

Periodicity

Protocols typically identify when GHG emissions must be measured. An initial measurement is needed to establish the baseline. This must be done prior to the onset of a project, to allow for measuring the *change* that results from the action. Occasionally, a historic baseline is specified; for example, the Kyoto Protocol identified 1990 emissions as the baseline for measuring emission reductions. Other options include a current level, or other level whereby a project is compared to "business as usual." The protocols also identify the frequency and timing of measurements. For example, CCX contracts for agricultural projects require annual measurements to assure that the emission reduction or carbon sequestration is actually occurring.

Frequency of measurement also depends on the rate of change in carbon storage. Some carbon pools, such as forest soils, change relatively slowly (unless the forest is disturbed), and measurement once a decade may be sufficient. For other carbon pools, such as pastures or managed lands, differences within and across years can be substantial, and may require more frequent measurement. Timing can be critical, and alternative measurements may vary widely. The amount of carbon stored in vegetation, in particular, varies over the course of a year, with carbon sequestered during the spring, carbon stored in foliage at its maximum in late summer, and carbon released during the winter as the deciduous leaves decompose. Thus, consistent timing for annual measures is an important element for agricultural and forestry carbon projects.

Verification

Verifying the emission reduction or carbon sequestration is critical in efforts to mitigate climate change. It is particularly important for agriculture and forestry projects, as these activities are harder to measure reliably than other types of GHG offsets. One question is who will be responsible for verifying changes in carbon, which raises questions about the role of a regulatory agency for accrediting claimed changes in carbon levels from an activity.

Existing programs typically recommend or require that the carbon offset be verified by an independent entity. Independent verification may be an auditing function, to assure the reality and accuracy of the carbon offset for markets (buyers and sellers), regulations (emitters and regulators), and reports (emitters and reporting organizations).[10] One source has prescribed several qualities for independent verification: an "independent, qualified, third-party verifier" using "approved methodologies and regulations" and "whose compensation is not in any way dependent on the outcomes of their decisions" and who follows set procedures to avoid conflicts of interest.[11]

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[9] See Suzie Greenhalgh et al., *The Greenhouse Gas Protocol: The Land Use, Land-Use Change, and Forestry Guidance for GHG Project Accounting*, World Resources Institute, Oct. 2006.

[10] Zach Willey and Bill Chameides, eds., *Harnessing Farms and Forests in the Low-Carbon Economy: How to Create, Measure, and Verify Greenhouse Gas Offsets*, Nicholas Institute for Environmental Policy Solutions, 2007.

[11] Offset Quality Initiative, *Ensuring Offset Quality* (July 2008), at http://www.pewclimate.org/.

As voluntary and regulated markets for GHG emissions offsets develop, qualified, independent organizations to verify carbon offsets will be needed. Entities qualified to verify agriculture and forest carbon offsets must be proven to be knowledgeable about carbon measurement. One source notes: "To provide good quality and trustworthy oversight, a sufficiently rigorous accreditation process will be necessary to ensure that the verifiers have the needed expertise."[12] This process could parallel the development of independent auditors for certifying sustainable forestry programs.[13]

Measurement Techniques

Basic approaches for measuring agricultural and forest carbon inventories and change include on-site measurement, indirect measurement from off-site tools, and estimation using process models or inferences. A hybrid approach involving a combination of approaches (e.g., combining modeling with on-site sampling and independent verification) might improve the accuracy enough to be useful while still containing costs. Because of the inherent challenges associated with balancing the cost of measuring carbon and the accuracy of these measurements, any practicable system for measuring forest and agricultural carbon might require a mix of these different methods and approaches, rather than a single approach.

On-Site Measurement

Direct measurement of the carbon content of agricultural and forestry soils and vegetation through field sampling and site-specific laboratory estimates is perhaps the most accurate way to measure carbon levels and changes. However, this is time-consuming, costly, and often requires continuous sampling and replication via a census of soil and vegetation carbon for all agriculture and forestry projects, and may be infeasible. Also, it cannot cover large areas. Samples can be taken and the results extrapolated, based on soil survey, land cover, climate, and other spatial data. Sampling patterns (e.g., a grid, random, or stratified random), intensity (e.g., the area to be sampled), and frequency are likely to be specified in the protocols, and many sources discuss sampling methods for agriculture and forestry projects.[14] The more intensive and frequent the sampling, the greater the cost, but the higher the likely accuracy of the data. Most experts suggest some sampling to ensure the accuracy of models or off-site measures, especially performed consistently over time.

As with verification, the entity that measures the on-site carbon can affect perceptions of the accuracy of the measurement. Landowners or other offset sellers can perform the measurement—both at the outset of the project (for the baseline) and periodically during the life of the project. This could reduce costs, because they are commonly on the site, but raises questions of credibility, since they have an interest in the reported carbon levels. Ensuring that verification is conducted by independent verifiers might be sufficient to assuage market concerns over credibility, but could involve high project verification costs.

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[12] Lydia Olander et al., *Designing Offsets Policy for the U.S.: Principles, Challenges, and Options for Encouraging Domestic and International Emissions Reductions and Sequestration from Uncapped Entities as Part of a Federal Cap-and-Trade for Greenhouse Gases,* Nicholas Institute for Environmental Policy Solutions, May 2008.

[13] For more information on forest certification, see http://www.pinchot.org/project/59.

[14] For examples of the latter, see *Harnessing Forest and Farm Carbon*; *GHG Project Accounting*; and *Sourcebook for LULUCF Projects*.

Indirect Measurement with Off-Site Tools

Tools exist to calculate carbon content without actually being on the site. Remote sensing—using photographic and other images from aircraft or satellites—can be used to measure carbon-related factors. For example, infrared imagery can detect live biomass, with variations in the image reflecting variations in the type and level of biomass. Remote sensing has long been used in forestry for calculating commercial timber volumes of forest stands.

The principal advantage of remote sensing is coverage, given its ability to assess a wide area relatively quickly. Another advantage is that the remote sensing and the analysis of the results are generally performed by experts, improving the credibility of the results and probably lowering the cost of verification. It can provide highly accurate information for some types of carbon-related measures, such as activities with readily visible results (e.g., deforestation and afforestation) or measurable carbon pools (e.g., live above-ground biomass). One disadvantage is the high fixed cost of providing remote coverage; satellites are very expensive to launch and maintain. Aircraft may be less expensive but may cover less area. Once the satellites are in place, extending satellite coverage to additional areas is relatively inexpensive. For some carbon-related measures, such as activities with less visible impacts (e.g., sustainable forestry) or less readily measurable carbon pools (e.g., soil carbon), remote sensing is problematic. Also, in some areas, cloud cover can interrupt regular measurements. Methods for consistently and reliably interpreting remote imagery are still under development, and are usually recommended to be used in conjunction with other techniques.

Estimation Using Process Models or Inferences

Another indirect approach is to estimate agricultural and forestry carbon with models or other analytical tools. Models are available to estimate a variety of ecosystem processes, and are used to depict site-specific conditions. Models, especially computer models, are typically built from extensive research and data sets, and provide average or archetypical estimates of physical area, temperature, precipitation, forest or soil type, slope, plant diversity, and microbial activity. The accuracy of the results depends in large part on the validity and measurement of the input variables for the model. Data may be presented in tabular form, called “look-up tables” because estimates can be looked up in the table based on a few key variables, such as forest type and tree age or soil type.[15] A related simpler approach might use inferences or generalized input data scaled up to the size of the farm or forested area to approximate the sequestration for an activity.[16] Such an approach may reduce costs, but provide a relatively low level of precision, and possibly high verification costs.

The advantage of a modeling approach is that it is relatively simple and low-cost, and often provides consistent estimates. However, it may not reflect actual differences within and across sites and activities, since it relies on archetypical or average carbon estimates and not site-specific carbon measurements. Model proponents often suggest using occasional site-specific sampling to assure the validity of the model chosen for the project and site, and some suggest adjusting the

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[15] James E. Smith et al., *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*, Gen. Tech. Rept. NE-343, April 2006.

[16] See, e.g., U.S. Dept. of Energy, *Technical Guidelines Voluntary Reporting of Greenhouse Gases (1605(b)) Program*, January 2007, http://www.pi.energy.gov/enhancingGHGregistry/documents/January2007_1605bTechnicalGuidelines.pdf.

estimates based on the samples. This introduces the potential for bias in reporting carbon, and significantly increases the difficulty of verification. In addition, for most situations and project types, numerous models exist. These competing models may yield quite different estimates for the same site, because of the different data sets and assumptions used in constructing the models. One model may yield the most accurate estimates in certain circumstances, while another model may yield more accurate estimates in other circumstances.

Considerations for Congress

Congress has already taken steps to address some of the challenges associated with measuring carbon changes from forested and agricultural lands and practices. The 2008 farm bill (P.L. 110-246, the Food, Conservation, and Energy Act of 2008) includes a provision (Sec. 2709) directing USDA to "establish technical guidelines that outline science-based methods to measure the environmental services benefits," including carbon storage, from forests and agricultural activities. This includes developing measurement procedures and a reporting protocol and registry.[17] The Energy Independence and Security Act of 2007 (P.L. 110-140, Sec. 712) directs the Secretary of the Interior to develop a methodology to assess carbon sequestration and emissions from ecosystems. This methodology is to cover measuring, monitoring, and quantifying GHG emissions and reductions, and provide estimates of sequestration capacity and the mitigation potential of different ecosystem management practices.

Agricultural/Forestry Offsets and Allowances: Areas of Concern

- ***"Measurement"/Accounting—***measurement is difficult and estimates can vary; actual uptake depends on site-specific factors (e.g., location, climate, soil type, crop/vegetation, tillage practices, farm management, etc.); and effectiveness depends on the type of practice, how well implemented, and length of time practice is undertaken.
- ***Validation/Verification—***reduction/storage activity must be real and measurable.
- ***Monitoring/Enforcement***—reduction/storage activity must be monitored and enforced by authorities or through contracts.
- ***"Additionality"/"Double counting"***—some activities generating offsets would have occurred anyway under a pre-existing program or practice, and may not go "beyond business as usual" (BAU); and reductions may be double-counted or attributable to other environmental goal/ programs.
- ***"Permanence"/Duration***—land uses can change over time (e.g., forest lands to urban development, natural events such as fires or pests); and benefits may accrue over time; some contracts shorter-term.
- ***"Leakage"—***reductions one place may cause additional emissions elsewhere.

[17] For more information on this farm bill provision, see CRS Report RL34042, *Provisions Supporting Ecosystem Services Markets in U.S. Farm Bill Legislation*, by Renée Johnson.

Congress continues to face the question of whether its current authorized activities provide adequate and sufficient guidelines for accurately measuring carbon levels from forest and agricultural activities.

The **Appendix** provides an annotated assessment of a range of agricultural and forestry activities, describing potential considerations according to measurement (quantification, verification, and monitoring), additionality, permanence, and leakage. The text box below provides a brief description of these different criteria. For more background information, see CRS Report RL34241, *Voluntary Carbon Offsets: Overview and Assessment*, by Jonathan L. Ramseur.

Appendix. Forestry and Agricultural Activities for Carbon Sequestration and/or Emission Reduction

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Forestry Activities						
Afforestation/Reforestation						
Afforestation	Fairly complicated; acreage treated is easy, but most models measure only commercial products, not all biomass.	Relatively easy via remote sensing with some on-site inspection. Can be difficult to distinguish from reforestation.	Fairly complicated; must track growth [of all biomass] periodically. Must account for losses to fire, insects.	Relatively easy; must account for losses from land conversion to forest, if any.	Long term—20 to 200 years or more—but not permanent.	No problem.
Reforestation	Fairly complicated; acreage treated is easy, but most models measure only commercial products, not all biomass.	Relatively easy via remote sensing with some on-site inspection. Can be difficult to distinguish from afforestation.	Fairly complicated; must track growth periodically. Must account for losses to fire, insects.	Complicated; must account for carbon release from logging. (See long-term wood products and reduced impact logging, below).	Long term—20 to 200 years or more—but not permanent.	No problem.
Forest Management						
Harvesting for Long-Term Wood Products	Complicated; production is easy; quantifying unused woods is difficult.	Fairly complicated; long-term use must be verified by end users.	Complicated; must track long-term end use.	Possibly no additionality. Unclear whether harvest for long-term use is additional to business-as-usual.	Possibly permanent, but most wood products eventually deteriorate.	No problem.
Delayed Timber Harvesting	Fairly complicated; treated area is easy, but carbon capture is difficult to quantify.	Relatively easy via remote sensing with some on-site inspection.	Fairly complicated; must track growth periodically. Must account for losses to fire, insects.	Possibly no additionality. Unless harvest is scheduled, may not be additional to business-as-usual.	Variable; could be very long-term (200 years or more), but could be very short-term (days or weeks)	Significant problem. Harvest could shift to other areas.
Reduced Impact Logging	Complicated; treated area is relatively easy, but impacts [reduced waste] are difficult to quantify .	Complicated; requires on-site inspection.	Easy: ongoing treatment with third-party verification.	Relatively easy; must account for change in carbon release from standard logging.	Long term—20 to 200 years or more—but not permanent.	Complicated; added costs could shift harvest sites.

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Certified Sustainable Forestry	Complicated; treated area is easy, but carbon capture is difficult to quantify.	Easy; independent third-party verification already required.	Easy; independent third-party verification already required.	Fairly complicated; must account for change in carbon release from standard forest management.	Possibly permanent, but landowner could terminate at any time.	Complicated; added costs to get certified could lead to shifting more logging to other areas.
Thinning/ Release—Mechanical	Fairly complicated; treated area is easy, but carbon capture & release are difficult to quantify.	Relatively easy via remote sensing with some on-site inspection.	Fairly complicated; must track growth periodically.	Possibly no additionality. Unclear whether thinning is additional to business-as-usual.	One-time treatment with continuing long-term effects.	No problem.
Thinning/ Release—Chemical	Fairly complicated; treated area is easy, but carbon capture & release are difficult to quantify.	Fairly complicated; requires on-site inspection.	Fairly complicated; must track growth periodically.	Possibly no additionality. Unclear whether thinning is additional to business-as-usual.	One-time treatment with continuing long-term effects.	No problem.
Thinning—Prescribed Burning	Fairly complicated; treated area is easy, but carbon capture & release are difficult to quantify.	Relatively easy via remote sensing with some on-site inspection.	Fairly complicated; must track growth periodically.	Possibly no additionality. Unclear whether prescribed burning is additional to business-as-usual.	One-time treatment with continuing long-term effects.	No problem.
Pruning	Complicated; treated area is easy, but carbon capture & release are difficult to quantify.	Fairly complicated; requires on-site inspection.	Complicated; must track growth periodically.	Possibly no additionality. Unclear whether pruning is additional to business-as-usual.	One-time treatment with continuing long-term effects.	No problem.
Fertilization	Fairly complicated; treated area is easy, but carbon capture is difficult to quantify.	Fairly complicated; requires on-site inspection.	Complicated; must track growth periodically.	Possibly no additionality. Unclear whether fertilization is additional to business-as-usual.	One-time treatment with continuing long-term effects.	No problem.

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Reduced Emissions from Deforestation and Forest Degradation (REDD)						
Avoided Deforestation	Relatively easy; total biomass carbon in tropical forests is easier to measure.	Relatively easy via remote sensing with some on-site inspection.	Fairly complicated; must track growth periodically.	Unclear; other programs exist to preserve forest lands.	Could be permanent, but could also be very short term.	Significant problem. Harvest can be shifted to unprotected areas.
Avoided Forest Degradation	Complicated; treated area can be measured, but carbon capture & release is difficult to quantify.	Complicated; requires on-site inspection.	Fairly complicated; must track growth periodically.	Unclear; other programs exist to preserve forest lands.	Could be permanent, but could also be very short term.	Significant problem. Harvest can be shifted to unprotected areas.
Agricultural Activities						
Land Retirement, Conversion, and Restoration						
Land Retirement	Relatively easy, given an established knowledge-base on how to measure and generate benefits using certain management techniques/practices.	Relatively easy, given an established knowledge-base. May require on-site sampling.	Relatively easy, since land is idle, and disturbance is relatively easy to detect.	Complicated. If getting payments or benefits under CRP and CREP, might not be "beyond BAU" (but could encourage environmental stewardship that may not happen otherwise).	Somewhat long term, but contract terms vary from 10- to 15-years. Favorable market prices for crops may encourage some farmers to exit contracts early or not to re-enroll.	Not expected to be a problem (although land use changes could have possible spillover effects, e.g., land taken out of production will be replaced elsewhere, either domestically or internationally).

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Conversion to Grasslands, Rangelands, or Pastureland; also Grasslands Restoration	Relatively easy, given an established knowledge-base on how to measure and generate benefits using certain management techniques/practices.	Fairly complicated since land is still actively used. May be complicating factors, such as endangered species, overgrazing issues, etc. May require additional field management and on-site sampling.	Fairly complicated, given certain complicating factors, and need for specific expertise in oversight issues.	Complicated. If getting payments or benefits under GRP, might not be "beyond BAU" (but could encourage environmental stewardship that may not happen otherwise).	Somewhat long term, but contract terms vary depending on whether an easement or rental (10-, 15-, 30-year, permanent) or if a restoration project. High market prices for crops may encourage early exit or not to re-enroll.	Not expected to be a problem (although land use changes could have possible spillover effects, e.g., land taken out of production will be replaced elsewhere, either domestically or internationally).
Other Cropland Changes (e.g., shifting between crops; transitioning to organic production or improved pasture)	Difficult to quantify, given the need to account for site-specific conditions based on the type of production change.	Difficult. Credible standards/protocols need to be designed and adopted. These need to account for differences in site-specific conditions. May require additional field management and on-site sampling.	Fairly complicated, given the possible range of practices, and need for specific expertise in oversight issues.	Complicated. If installed under existing USDA financial/technical "working lands" assistance programs (EQIP, CSP, AMA), may not be "beyond BAU" (but could encourage environmental stewardship that may not happen otherwise).	May or may not be long term. Depends on how long farmer maintains practice, whether leases/owns land, or if chooses to respond to other market conditions. Most cost-share contracts are <5 yrs. Could be easy to discontinue practice in some cases.	Not expected to be a problem (although land use changes could have possible spillover effects, e.g., land taken out of production will be replaced elsewhere, either domestically or internationally).

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Wetlands Restoration	Difficult to quantify, given the number of recognized wetlands attributes/functions.	Fairly complicated, given differences based on multiple standards/protocols. May require additional field management and on-site sampling.	Fairly complicated, given differences in multiple standards and site—specific conditions.	Complicated. If getting payments and benefits under WRP, may not be "beyond BAU" (but could encourage environ-mental stewardship that may not happen otherwise).	Somewhat long term, but contract terms vary depending on easement terms (30-year, or permanent) or if a restoration project (generally 10-year minimum).	Not expected to be a problem (although land use changes could have possible spillover effects, e.g., land taken out of production will be replaced elsewhere, either domestically or internationally).
Selected Structural Barriers (vegetative, riparian buffers, windbreaks), **Set-backs**	Relatively easy, given established standards/practices.	Relatively easy, given established standards/practices. May require on-site sampling.	Fairly complicated, given the possible range of practices, and the need to account for site-specific conditions. Could require specific expertise in oversight issues.	Complicated. If installed under existing USDA financial/technical "working lands" assistance programs (EQIP, CSP, AMA, WHIP), may not be "beyond BAU" (may encourage environ-mental stewardship that may not happen otherwise).	Typically a one-time treatment with possible continuing long-term effects, assuming structure is properly maintained. In case of set-backs, land may be put into back into production, and discontinue practice.	Not expected to be a problem (although land use changes could have possible spillover effects, e.g., land taken out of production will be replaced elsewhere, either domestically or internationally).

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Cropping Practices and Soil Management						
Tillage practice: Conventional versus Conservation Tillage (no-till, reduced-till, medium- till, strip/ridge-till)	Difficult, given need to account for site-specific conditions (soil, slope, rainfall, temperature, crop type, microclimate, microbial activity, etc.) for each type of tillage practice. Requires the use of complex, integrated modeling (ongoing debate about best model and available default factors).	Fairly complicated. There are established standards, but differences in how implemented and managed. Since land is still actively used, could complicate an assessment. May need to consider differences in site-specific conditions, which could require field management and site sampling.	Difficult. Because it is a relatively cheap and simple practice to implement, many farmers would likely participate (based on high participation rates in voluntary markets). Volume of projects could complicate oversight and independent verification.	Complicated. If installed under existing USDA financial/technical "working lands" assistance programs (EQIP, CSP, AMA), may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	May or may not be long term. Depends on how long farmer maintains practice, whether farmer leases or owns the land, whether farmer chooses to respond to market conditions, or whether able to withstand lower yields in near-term. Easy to discontinue. Most cost-share contracts are <5 yrs.	Land use changes could have possible spillover effects in the short-term, e.g., if yields are reduced, additional production is needed elsewhere, either domestically or internationally).
Soil Supplements/ Amendments (e.g., biochar, lime)	Fairly complicated. Some technologies remain an emerging technology. Others require the need to account for site-specific conditions	Difficult. Credible standards/protocols need to be designed and adopted. These need to account for differences in site-specific conditions. May require additional field management and on-site sampling.	Fairly complicated, given the possible range of practices, and the need to account for site-specific conditions. Could require specific expertise in oversight issues.	Complicated. If installed under existing USDA financial/technical "working lands" assistance programs, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Somewhat long term, but may rely on financial assistance under USDA financial/technical "working lands" assistance programs. Most cost-share contracts are <5 yrs. Easy to discontinue practice.	Not expected to be a problem.
Precision Agriculture Practices, BMPs (fertilizer, nutrient, and chemical application)	Fairly complicated. An established knowledge-base exists, but remains an emerging technology.	Difficult. Common standards/protocols need to be designed and adopted. These need to account for differences in site-specific conditions. May require additional field management and on-site sampling.	Fairly complicated, given the possible range of practices, and the need to account for site-specific conditions. Could require specific expertise in oversight issues.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs (EQIP, CSP, AMA), may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Somewhat long term, but may rely on financial assistance under USDA financial/technical "working lands" assistance programs Most cost-share contracts are <5 yrs. Could be easy to discontinue practice in some cases.	Not expected to be a problem.

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Soil Erosion Controls (incl. cover cropping)	Fairly complicated. An established knowledge-base exists, but needs to account for site-specific conditions (soil, slope, rainfall, temperature, crop type, microclimate, microbial activity, etc.).	Fairly complicated. Standards/protocols exist, but vary by type of practice and by land type (and other site-specific conditions). May require additional field management and on-site sampling.	Fairly complicated, given the possible range of practices, and the need to account for site-specific conditions. Could require specific expertise in oversight issues.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs (EQIP, CSP, AMA), may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Somewhat long term, if farmer maintains practice as part of ongoing operations. May require financial assistance under USDA "working lands" assistance programs. Most cost-share contracts are <5 years. Could be easy to discontinue practice.	Not expected to be a problem.
Animal Manure and Feed Practices						
Livestock Manure Management and Storage, Anaerobic Systems (e.g, digesters, closed poultry houses, CH_4 recovery)	Relatively easy, but depends on type of system (lagoon, pit, digester), type of animal, and waste stream (dry, solid, liquid, slurry, bedding).	Relatively easy, given established standards/practices under most tested, engineered systems.	Relatively easy. Typically the cost of installing most high-end systems means there are few in operation, which simplifies overall enforcement.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs or using USDA loans/grants, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	One-time treatment with continuing long-term effects (typically high-end technology with high fixed startup and construction costs, with high annual operating costs).	Manure from these types of systems is mostly treated. If, however, untreated manure from these systems is land-applied and used in crop production, this could exacerbate local methane emissions in some cases.

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Livestock or Poultry Manure Management and Storage, Aerobic Systems (e.g, open-air lagoons, pits)	Relatively easy, but depends on type of system (lagoon, pit, digester), type of animal, and waste stream (dry, solid, liquid, slurry, bedding).	Fairly complicated. Standards exist, but vary by type of system, type of animal, and waste stream. May require additional field management and on-site sampling.	Fairly complicated, given the possible range of practices, and the need to account for site-specific conditions.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs or using USDA loans/grants, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Usually a one-time treatment with continuing long-term effects (typically fixed construction, startup and operating costs, although some farmers may decide to transition to a higher-end system to manage waste).	Manure from these types of systems is mostly untreated. If manure is land-applied for use as nutrients for crop production, this could exacerbate local methane emissions under some cropping systems.
Poultry Manure Management and Storage (e.g,. closed housing systems)	Relatively easy, but may depend on type of housing and ventilation system. Might vary by size of unit and bird type.	Relatively easy, given established standards/practices under most tested, engineered systems.	Relatively easy, given established standards/practices under most tested, engineered systems.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs or using USDA loans/grants, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	One-time treatment with continuing long-term effects (typically high-end technology with high fixed startup and construction costs, with high annual operating costs).	Not expected to be a problem, since manure is mostly treated and often has value as a soil amendment.
Livestock Feed Management (improved feed efficiency, dietary supplements to reduce CH_4 emissions (byproduct of animal digestion through enteric fermentation)	Relatively easy, based on recognized emissions factors and data (animal numbers and feed conversion efficiency). Varies by age and type of animal, and by production region.	Fairly complicated. Standards/protocols exist, but vary by type of practice and animal, and the precision how the practice is applied and managed. May require sampling.	Fairly complicated, given the possible range of practices. Could require specific expertise in oversight issues.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Depends on whether farmer maintains practice as part of ongoing operations. Could be easy to discontinue practice in some cases. May require financial assistance under USDA programs. Most cost-share contracts are <5 yrs.	Not expected to be a problem.

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
Grazing Feed Management (improved forage practices to control for enteric fermentation	Fairly complicated, based on recognized emissions factors and data (animal numbers and feed conversion efficiency). Varies by animal type and by production region. Field studies using a tracer technique may allow for estimation at the herd level.	Fairly complicated. Standards/protocols need to be designed and adopted, and need to account for differences in site-specific conditions. May require additional field management and on-site sampling.	Fairly complicated, given the lack of standards/protocols. Could require the need for specific expertise in oversight issues.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Depends on whether farmer maintains practice as part of ongoing operations. Could be easy to discontinue practice in some cases. May require financial assistance under USDA programs. Most cost-share contracts are <5 yrs.	Not expected to be a problem
Grazing Manure Management (rotational grazing to control direct manure deposits on pasture and rangelands	Difficult to quantify, given the need to account for site-specific conditions (soil, slope, rainfall, temperature, crop type, microclimate, microbial activity, etc.).	Fairly complicated. Standards/protocols need to be designed and adopted, and need to account for differences in site-specific conditions. May require additional field management and on-site sampling.	Difficult, given the lack of standards and protocols. Could require the need for specific expertise in oversight issues.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Somewhat long term, if farmer maintains practice as part of ongoing operations. Could be easy to discontinue practice in some cases. May require financial assistance under USDA programs. Most cost-share contracts are <5 yrs.	Land use changes could have possible spillover effects in the short-term, e.g., exacerbate local methane emissions if deposited waste is not well-managed).
Energy Use, Substitution, and Efficiency						
Biofuels Production/ Substitution (replacing fossil fuels with renewable energy sources)	Relatively easy. An established knowledge-base exists, but standards and a full accounting of farm-level energy use is needed.	Fairly complicated, given the need for a full accounting of farm-level energy use. Standards and protocols need to be designed and adopted.	Fairly complicated, given the lack of standards/protocols.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs or using USDA loans/grants, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Somewhat long term, if farmer maintains practice as part of ongoing operations. . May require financial assistance under USDA "working lands" assistance programs. Most cost-share contracts are <5 yrs.	Competition between food production and biofuel feedstocks production could increase production elsewhere, either domestically or inter-nationally.

Practice	Quantification	Verification	Monitoring	Additionality	Permanence	Leakage
						Diverting more land toward biofuels production, away from other uses (and land retirement) and the use of intensive cultivation to raise yields could have unintended consequences.
Energy Efficiency (on farm)	Relatively easy. An established knowledge-base exists, but standards and a full accounting of farm-level energy use is needed.	Fairly complicated, given the need for a full accounting of farm-level energy use. Standards and protocols need to be designed and adopted.	Fairly complicated, given the lack of standards/protocols.	Complicated. If implemented under existing USDA financial/technical "working lands" assistance programs, may not be "beyond BAU" (but may encourage environ-mental stewardship that may not happen otherwise).	Somewhat long term, if farmer maintains practice as part of ongoing operations. . May require financial assistance under USDA "working lands" assistance programs. Most cost-share contracts are <5 yrs.	Not expected to be a problem.

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