Appendix E: Discussion of Leakage Literature

Table of Contents

1. Introduction

The purpose of this appendix is to review the literature that discusses greenhouse gas (GHG) emissions leakage, which is an indirect source of biogenic CO_2 emissions associated with the production, processing, and use of biogenic material at stationary sources. Specifically, this appendix examines a range of studies that, using a variety of modeling approaches and scenario designs, evaluate how and why leakage occurs. There is a particular focus on indirect land use change (ILUC), which is an important form of leakage to consider when assessing biogenic CO_2 emissions from stationary sources. This examination is intended to help identify important factors that could be considered when assessing leakage and different methods that have been used to calculate emissions leakage in other contexts. In the event that policy- or program-specific applications of the framework necessitate calculations of leakage, the analysis here could inform such a process. This appendix considers both international and domestic (interregional) leakage for completeness.

Recognizing that leakage associated with bioenergy feedstock production can occur due to market and land use change induced by displaced feedstock or feedstock substitute production, the framework equation presented in this report includes a leakage term.[1] However, a specific quantification methodology recommendation is not provided in this report: the determination to estimate and include leakage in applications of the framework, as well as the methods to calculate it, will be policy- or program-specific.

The potential importance of leakage can vary across feedstocks and production circumstances. It is important to recognize that biogenic assessment factor (*BAF*) results may differ considerably for some feedstocks depending on treatment of leakage, but quantifying it is complex, as discussed in the literature review below.

The remainder of this appendix discusses the primary factors that typically contribute to leakage, provides an overview of relevant literature, and offers examples of different leakage analyses that have been conducted in different policy contexts and with different goals, assumptions, and parameters.

2. Background

Policies and programs typically have limited spheres of direct influence or scope and therefore may result in changes in activities outside their scope that can contribute to the net impacts of the action. Leakage is an indirect consequence of policies or behaviors that can and occur in many different contexts. Leakage effects could be positive (e.g., benefits of local tourism extending beyond the region or technological innovation spreading from one firm to others) or negative (e.g., reduced deforestation in one region is at least partially offset by increased deforestation in other regions as output prices rise). In the context of environmental policy, one of the key areas in which leakage has been examined in recent years is displacement of GHG-emitting activities to areas and/or sectors that are not covered by a policy, or program (Barker et al., 2007; Weber and Peters, 2009; Chen, 2009). There are different definitions of carbon leakage in the literature, but the International Panel on Climate Change (IPCC) Special Report on Land Use, Land-Use Change, and Forestry defines carbon leakage as "the indirect impact that a targeted LULUCF activity in a certain place at a certain time has on carbon storage at another place or time" (IPCC, 2000).

In the context of the framework and its focus on biogenic carbon and CO_2[2] emissions fluxes, leakage represents any biogenic CO_2 flux changes outside of a biogenic feedstock production assessment scope that can be attributed to the production activities (e.g., replacement of diverted crop, livestock, or forest products on other lands due to a change in land use from conventional commodity production to biogenic feedstock production for energy conversion).

If the assessment scope of the policy or program was global, then there would be no leakage because all emissions would be inherently captured within the assessment scope. In practice,

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[1] The *LEAK* term could be incorporated into the retrospective reference point and future anticipated baselines in different ways. For further information on the retrospective reference point baseline, see Appendix H. For further information on the future anticipated baseline, see Appendix J.

[2] The framework could potentially be expanded to include additional GHGs as appropriate for a particular policy application.

however, project assessment scopes are typically more limited. In some cases, especially where policies result in substantial price effects, there may be changes in activities and emissions that take place outside the defined assessment scope. The reason is that activities in regulated sectors/regions tend to shift to, or have influences on, sectors/regions outside the regulatory and/or assessment framework, particularly if there is reduced product availability from the regulated sectors/regions. In that case, there will tend to be price increases that will induce expanded production in other related sectors and in other regions.

Although outside of a project's direct control, emissions that are shifted to another location or sector may have an important effect on the project's net GHG benefits. One of the more important sources of leakage for programs or policies affecting land use is the impact on carbon storage due to shifting land use. Where land is changing uses due to these indirect pressures, this specific leakage effect is commonly referred to as ILUC. Depending on the lands being converted and biogenic material being produced, ILUC can cause net changes in GHG emissions or sequestration. Because leakage from additional biogenic feedstock production can potentially be significant, the framework in may need to consider including leakage for certain policy or program applications. Inclusion of leakage estimates would account for changes in GHG emissions from ILUC or other sources of leakage that occur outside of the biogenic feedstock production assessment scope.

3. Factors that Can Contribute to Leakage

In the general context of leakage related to GHG emissions globally, for example, as long as all emissions sources are governed by the same rules, shifting emissions from one region to another is perfectly acceptable and indeed represents a more economically efficient outcome (Murray, 2008). If all regions are covered by the same policy or assessment system, no leakage would occur, because all emissions would be accounted for (assuming full enforcement) (Murray, 2008). However, few policies have a global scope, making leakage difficult to avoid. Whenever incentives for action differ across potentially affected entities, there will be a tendency to shift activities that result in emissions from more highly controlled entities to less controlled entities. In general, leakage can erode net carbon reductions because "the spatial scale of intervention is inferior to the full scale of the targeted problem" (Wunder, 2008, p.65).

The primary driver of leakage is economic—in globally integrated markets, increased demand for a biogenic feedstock for energy within the assessment area may lead to increased production of that type of biomass and/or other changes in land use patterns outside the assessment boundaries. This is because increased demand for a biogenic feedstock for energy production triggers higher overall demand for the biogenic feedstock, thereby leading to higher commodity prices for that feedstock and its substitutes. These commodity price increases can lead to a succession of land-use changes to produce more feedstock, including the conversion of forest and other high-carbon storage ecosystems to lower carbon storage systems and the release of carbon stored in soils and vegetation. However, depending on the feedstock and time frame considered, it is also possible for positive leakage to occur. For instance, higher prices for forest biomass could lead landowners to convert a large enough area of agricultural lands to forests that regional carbon stocks are increased relative to baseline conditions.

Leakage effects, including ILUC, can also occur when lands and/or biogenic materials previously used for other purposes are instead diverted to biogenic feedstock production due to competition and resource scarcity. However, the market demand for the original product still exists and with higher commodity prices there is still an incentive for supply of the original product to approach the original quantity demanded. This additional demand can be met through intensification of existing lands producing the original product materials elsewhere or extensification, which means bringing new lands into production.

Agricultural and forest commodities are frequently traded in markets that operate at a local, regional, national, or global scale. As a result of this integration, changes in the supply and demand of commodities in one part of the world may be translated into changes in market supply and demand of the same and related commodities in other parts of the world. Policies targeting land use for specific activities in one location can induce a broader reallocation of land use unless such shifts are specifically and effectively restricted by the policy (e.g., Wu, 2000; Wear and Murray, 2004; Murray, McCarl, and Lee, 2004).

Similarly, substitutability and competition with other biomass types may lead to production changes beyond the assessment area because of potential product substitution (Latta et al., 2013). Land can be used to produce a wide array of forestry and agricultural products. Land cover and land use are expected to vary over time as land is allocated to activities that yield the highest net present value based on information available when the land use allocation decision is made. In addition, many forestry and agricultural commodities have other commodities that are at least partially substitutable for them (e.g., livestock feed can be made using a variety of grains and oilseeds, including corn, wheat, rye, barley, oats, soybeans, and others used in various combinations that meet livestock nutritional requirements). As a result, commodity prices are generally correlated due to adjustments taking place on both supply and demand sides as both buyers and sellers adjust to changing relative prices. Thus, there may be an associated emissions shift from assessed regions to unassessed regions due to land use change and other production-related activities. Ignoring leakage can make emissions fluxes from biomass use appear larger or smaller than they actually are, thereby potentially undercutting program objectives (Murray, 2008).

When these land-use transitions occur outside the assessment region, related GHG emissions fluxes may not be accounted for. Some of the literature indicates that biogenic feedstock production projects reduce GHG emissions to the atmosphere only if the net growth of harvesting of the biomass for energy captures carbon above and beyond what would be sequestered anyway (i.e., if sequestration is additional).[3] In one study, foregone sequestration is considered the equivalent of additional emissions, and when these emissions are associated with activities producing biomass,

[3] "Additionality" is a criterion for assessing whether an activity has resulted in GHG emission reductions or removals relative to what would have occurred in its absence. This is generally a more complex criteria for land-based mitigation activities than for point-source or facility-based activities because of the inherent dispersed, heterogeneous, dynamic, and systems-based aspects of agricultural and forestry production, but there are viable strategies for addressing additionality in these sectors (Janzen et al., 2012).

the author argues they should be included in GHG accounting associated with the biomass production (Searchinger, 2008).

"Leakage potential can be high if no counteracting provisions are put in place" (Murray, 2008, p. 10); and the economic forces driving leakage are interdependent and "difficult to restrain" (Murray, 2008, p. 18). According to some studies, when considering leakage, estimates should reflect the following elements: connectedness of output and land markets, mobility of labor and capital, consumer flexibility, producer flexibility, availability of alternative lands for production, and ability of producers to change their emissions profile without modifying production (Wunder, 2008; Henders and Ostwald, 2012).

The change in total cultivated land associated with a change in demand for bioenergy feedstocks will depend on a number of parameters, but one of the most important factors is the land supply elasticity. In cases where land supply is relatively elastic, there will be relatively large increases in supply of a given land type when the returns to that type of land increase. Landowners will shift their land cover and crop mixes to provide more of the commodities that are in greater demand. If land supply is relatively inelastic, on the other hand, then there will be a smaller response to changes in demand for individual commodities. The more competitive and integrated land markets are across regions, the larger the extent of leakage expected when different regions face different incentives to mitigate emissions. However, when considering leakage across regions, even when considering only a single type of biomass, it should be noted that there is a difference between shifts in production activity or area and net emissions. For example, even within the United States, shifting forestry area from the Southeast (SE) to Pacific Northwest (PNW) would likely reduce net carbon emissions, whereas the reverse would result in significant positive domestic leakage due to the lower carbon density of SE forests (summing across carbon contained in aboveground biomass, belowground biomass, deadwood, forest floor, and soil organic carbon) (Heath et al., 2011).

The elasticity of demand for conventional commodities must also be considered. In cases where demand is inelastic, the quantity demanded will change by a smaller percentage than prices rise. This inelastic behavior will result in a greater amount of leakage than in markets with more elastic demand. Higher production costs resulting in lower production levels in regulated regions will result in a great deal of shifting of production to regions unaffected or less affected by policies because the overall market demand does not decline much in response to higher prices. When demand is highly elastic, policy impacts that result in higher production costs and increased market prices will result in less production moving to other regions because the equilibrium quantity demanded will decline by a greater percentage than price increases. In addition to the own-price elasticity of demand, cross-price elasticities of demand for substitutes and complements are also important to consider. Not only will increases in the market prices of directly affected commodities potentially lead to increased production of those commodities into less directly impacted regions, but they will also impact production of complement and substitute commodities in other regions. Another important point of consideration is that as demand for a commodity increases, producers may intensify production practices (e.g., increase fertilization rates, use of irrigation, improved crop varieties, and other yield enhancements) because higher output prices make it profitable to engage in more intensive production practices requiring greater input expenditures. Achieving higher yields through intensification would limit direct and indirect land-use change (Searchinger, 2008) but may lead to other GHG fluxes (e.g., increased N_2O emissions from higher levels of nitrogen fertilization, higher CO_2 associated with greater fossil fuel use for irrigation). Thus, the net change in GHG emissions would depend on the relative changes in emissions across all relevant pools and intensification could either increase or decrease total emissions relative to extensification.

4. Overview of Relevant Literature

Although the concept of carbon emissions leakage in industrial sectors has been widely studied for over 20 years, the focus on leakage in land-using sectors has been more recent. There have been many studies of industrial carbon leakage ever since the United Nations Framework Convention on Climate Change was established in 1992, identifying differentiated responsibilities for reducing emissions, and the subsequent Kyoto Protocol was developed and agreed upon with emissions limits specified only for a set of developed countries. There is also extensive literature on the international trade and competitiveness under environmental policy going back to the 1980s, although this literature on "pollution havens" was not typically focused on global pollutants and often not explicitly focused on implications for total emissions as much as distributional impacts of polluting industries' potential relocation between states or countries.

Interest in leakage associated with land-using sectors has grown considerably in the last decade with the development and implementation of bioenergy policies and international policy interest in reducing emissions from deforestation and land degradation (REDD+). In this section, an overview of the literature on leakage associated with land use and potential relevance is provided, followed by brief sections summarizing some of the recent relevant literature focused on agriculture and forestry applications.

4.1. Literature Research on Leakage

A full accounting for leakage associated with land use and related GHGs is very complex because of the multiple affected markets, heterogeneity, dynamics, and numerous interactions. The literature offers an incomplete picture of leakage magnitude and what can be done to minimize negative leakage (Kim and Dale, 2011; Murray, 2008). Furthermore, the precise meaning of the term "leakage," both in terms of scale and scope, can fluctuate from study to study, making direct comparisons difficult.[4] Finally, few studies mirror the feedstock sub-delineations used in the framework report, thereby complicating evaluations of feedstock-specific applicability.

Because the primary bioenergy, REDD, and other forestry and agriculture policies of interest for leakage assessment have typically been implemented relatively recently, time series data for empirical analysis are limited. Typically, the policies being considered do not have direct historical precedent and would result in new markets being created, which results in changes in market and

[4] "Leakage" sometimes refers simply to indirect land-use change but can also be used along with carbon debt or market price impacts. If GHG emissions from all regions are accounted for in a consistent manner and reflected under a regulatory framework, then there could be indirect land-use change without carbon leakage (because any changes in emissions associated with indirect land-use change have been reflected in GHG accounting).

land use activities that fall outside past experience and limits the ability of statistical analyses of existing data to explain future outcomes. Data limitations, along with the complexity of adequately reflecting relevant factors influencing market outcomes and land dynamics, have resulted in there being a limited empirical literature on leakage in land-based sectors. Absent empirical data from representative case studies, leakage estimates have instead employed a variety of economic land use models covering the agricultural, forestry and other land use sectors, such as, the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG), the Food and Agricultural Policy Research Institute (FAPRI) model, and the Global Trade Analysis Project (GTAP) general equilibrium model. These economic models vary widely in terms of model type, inputs, and assumptions, as well as scope and scale in terms of output. In addition, many of the existing economic land use models do not fully account for all GHG emissions associated with the market activities being modeled. Therefore, in some applications, the changes in market activities and land use simulated using the models have been combined with emissions factors available in models such as the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model in order to estimate net changes in GHG emissions.

Such models can lend insights as to the possible directionality and/or general magnitude of leakage. However, leakage affects multiple markets and regions simultaneously, thereby increasing the complexity of model projections and making it difficult to isolate the causes and effects of market and land-use shifts and related leakage. The results are largely case-specific, and depend greatly on context and the assumptions of each particular study.

In countries where land use is highly regulated and controlled with few linkages to international markets, it may be easier to estimate (and control) leakage. When land use change occurs in an unplanned and unpredictable manner across numerous countries (e.g., indirect land-use change caused by bioenergy development), detecting leakage is particularly difficult and involves many different measurements and analyses to adequately represent and understand the land use and emission dynamics. Many studies project multiple scenarios using many different assumptions as sensitivity analyses to reflect parameter uncertainty. Because of this and the aforementioned variability in how leakage is defined and measured, there is considerable inconsistency surrounding leakage estimates (e.g., Plevin et al., 2010).

4.2. Leakage Literature: Agriculture

There has been a growing amount of attention and research effort devoted to the effects of policies affecting the demand for agricultural commodities on land use change, particularly in the context of increased demand for biofuels (e.g., ethanol and biomass-based diesel). Notably, EPA includes estimates of land use change due to increased demand of specific biofuels (e.g., corn ethanol) as part of the GHG accounting applied for Renewable Fuel Standard (RFS2) feedstock analyses (EPA, 2010), as described in more detail in Section 5.1.1. Partly because of the implementation of RFS2 and biofuels policies in the European Union, Brazil, and elsewhere in recent years, there has been a great deal of interest in indirect land use change and leakage associated with bioenergy policies.

The existing literature assessing potential leakage magnitude from corn ethanol production shows that estimates differ considerably across studies and within a study depending on underlying assumptions (Khanna et al., 2011; Khanna and Crago, 2012). Searchinger et al. (2008, 2009) and Fargione et al. (2008) are frequently cited studies among the first to challenge the net benefits associated with biofuels on the basis that indirect land use and GHG emissions from land use conversion were not being fully captured and to quantify the impacts. For instance, Searchinger et al. (2008) combines calculated changes in land use they estimate are necessary to meet required increases in U.S. corn ethanol volumes with emission factors from the GREET lifecycle model to project changes in net GHG emissions resulting from an increase in U.S. corn ethanol production. Searchinger et al. (2008) calculated that a 56 billion liter increase in ethanol production would divert corn from 12.8 million ha (hectares) of U.S. cropland. This would in turn bring 10.8 million ha of additional land globally into cultivation, including 2.8 million ha in Brazil, 2.3 million ha in China and India, and 2.2 million ha in the United States. The emissions associated with converting this land represent leakage (aside from direct land use change for corn production in the United States), but the true magnitude of the leakage depends on the nature of the land-use change (i.e., what type of land is being converted). They assumed the conversion of forest to cropland releases 604 to 1,146 metric tons CO_2e per ha, while the conversion of grassland/savannah to cropland releases 75 to 305 metric tons CO_2e per ha.

Regardless of the type of land converted, the payback period for these up-front emissions can be very long. Using an average of 351 metric tons CO_2e per converted ha, Searchinger et al. (2008) estimated "carbon neutrality" for corn-based ethanol only after 167 years. Using the standard 30-year time frame, corn-based ethanol results in a 93% increase in net emissions compared with business-as-usual gasoline consumption. This study also ran a sensitivity analysis that includes 20% increases in grain yields, land-use emissions reduced by half, and process efficiency gains of 40%. In that best-case scenario, net emissions approach those of gasoline after 30 years.

A key driver of the results in each of these studies is that expanded corn ethanol production in the United States will substantially reduce U.S. corn exports, leading to expanded foreign corn production. They assumed that foreign countries will convert natural vegetation to croplands, including tropical rainforests and other high carbon density areas, which results in very large carbon emissions (Searchinger et al., 2008, 2009; Fargione et al., 2008).

However, a number of subsequent studies have critiqued some of the assumptions used in Searchinger et al. (2008) (e.g., Wang and Haq, 2008) and many subsequent studies provide alternative estimates of ILUC and leakage. Some of the key considerations influencing ILUC include assumptions regarding price elasticities, yield improvements over time, the substitution rate of dried distillers grains for corn, the types of land that are converted, GHG calculations, and long-term land dynamics in response to changing incentives, among others.

For instance, Hertel et al. (2010) employed an approach similar to Searchinger (2008), but used different assumptions about the land that will be converted to agriculture. Importantly, Hertel et al. (2010) relied on the GTAP-BIO version of the GTAP model, a general equilibrium agricultural economic model that provides more land use data and economic details of land use than the more basic assumption about land requirements used by Searchinger (2008). Whereas Searchinger (2008) estimated most conversion will be either forest to cropland or grassland to cropland, Hertel et al. (2010) estimated that much of the cropland transition will actually stem from degraded, pasture, or other low-carbon lands, which substantially reduces emissions from indirect land use change. Studies such as Potter et al. (2007) and Aguilar et al. (2012) have estimated significant quantities of marginal lands in the United States that they argue could be converted to biomass production, which would substantially reduce pressure for conversion of higher carbon density forests and grasslands. However, it is also important to consider the economic incentives facing landowners. The fact that it is physically possible to grow bioenergy crops on marginal lands does not mean landowners will choose to do so if it is more profitable to grow them on more productive croplands.

Drabik and de Gorter (2011) also measured carbon leakage associated with biofuels (specifically, corn-based ethanol), but instead of land-use change they focused on the market response to corresponding changes in fuel prices. Specifically, if fuel prices decline as a result of increased ethanol production, then total fuel consumption will presumably increase (i.e., the rebound effect). As a result, 1 gallon of ethanol does not replace 1 gallon of gasoline. Instead, because of the price impact, Drabik and de Gorter (2011) showed 1 gallon of ethanol replacing only 0.35 to 0.5 gallons of gasoline. Thus, although average per gallon carbon intensity of fuel may decrease as a result of ethanol, overall fuel consumption may increase and could potentially overwhelm these reductions.

In another application examining potential domestic leakage of environmental policy, Wu (2000) analyzed domestic leakage related to the U.S. Conservation Reserve Program (CRP) and found that for every 100 acres of cropland retired under CRP in the central United States, about 20 acres of non-cropland were converted to cropland. This leakage effect was estimated to offset about 9% of the CRP water erosion benefits and 14% of the wind erosion benefits.

4.3. Leakage Literature: Forestry Sector

Similar to the agricultural sector, policies affecting forest use in one place are expected to impact forest management decisions elsewhere. In particular, there has been a great deal of interest in quantifying the extent to which forest conversation measures in one location induce greater timber harvesting elsewhere. Many carbon leakage studies have focused on the forestry sector.

Murray, McCarl, and Lee (2004) developed a conceptual model for analyzing market adjustments and carbon leakage. They also applied FASOM to empirically estimate leakage from different forest preservation strategies in the United States. They estimated leakage for U.S. carbon sequestration policies and found leakage rates varying from less than 10 to over 90% depending on policy specifications and region(s) of the country where the policy is implemented. Alig et al. (1997) also applied FASOM and found that carbon benefits from expanded U.S. afforestation would largely be offset by converting existing forestland to agriculture. Wear and Murray (2004) explored the effects of public forest conservation in the U.S. Pacific Northwest on forest production and markets in the United States and Canada. They found that a total of about 84% of reduced public harvest would be replaced by increased private harvest, and around 58% of reduced public harvest would be replaced within the United States and another 26% in Canada.

Sohngen and Brown (2004) examined leakage associated with a specific tropical forest conservation project in Bolivia. They developed a dynamic timber market optimization model and ran the model using differing assumptions about global policies, capital constraints, demand elasticity, and deadwood decomposition rates. Overall, they found leakage rates of 5 to 42% for this project-level assessment. Leakage is lowest when demand is more elastic and wood decomposition rates are faster.

There have also been a number of recent studies examining leakage associated with forestry policies at the global level. Gan and McCarl (2007) estimated international leakage with the GTAP general equilibrium model. They defined leakage in terms of forest production rather than emissions, but the changes in forest production from their model would clearly have implications for GHG emissions. They examined lumber, paper, and log markets and analytically derived the transnational leakage and applied GTAP to estimate leakage at a global level. The study concludes that leakage is related to assumptions about the elasticities of demand and supply of forestry products, lumber and wood products, and pulp and paper products across many countries. They also note that cooperation among countries tends to alleviate leakage. Under current global trade conditions, they estimated leakage rates ranging from 42 to 95% with leakage rates above 70% for the majority of regions. Because they are defining leakage in terms of forest products production, carbon leakage may be even greater if forest production is shifting to less efficient production regions and/or regions with higher carbon density. Sun and Sohngen (2009) use a global land-use forestry model to estimate global leakage emanating from three different forestry set-aside scenarios and find that leakage could be nearly 100% in the near term under one of the global policies examined. Sohngen and Sedjo (2000) showed the impact of increased demand on harvests and management of industrial forests in regions around the globe. Their model showed significant GHG emissions from boreal and temperate forests, but this impact was dampened by the rising influence of subtropical plantations. Overall, they found carbon leakage to be less than 16%.

In addition, several recent studies have identified the potential for increased bioenergy demand to raise biomass prices sufficiently to induce greater levels of afforestation and more intensive forest management to the extent that total carbon stocks are actually increased (Daigneault, Sohngen, and Sedjo, 2012; Sedjo and Tian, 2012; Sedjo, Sohngen, and Riddle, 2013). There may be a short-term reduction in forest carbon as harvesting increases but greater sequestration in the long term as forest area and carbon densities increase.

5. Examples of Leakage Analysis

Although the development and implementation of a land use analysis that adequately reflects leakage is a very complex endeavor, there are cases where leakage has been estimated and used in calculations of net GHG emissions profiles for both policy analyses and carbon accounting protocols. Several examples are presented below.

5.1. Policy Analyses that Include Leakage

There are a number of examples of policies and programs that take leakage into account. However, the methodological approach of each program is carefully tailored to meet the program or policy's requirements that the analysis is being designed to serve. As such, these methodologies may differ in several ways, including technical assumptions used, models (and types of models) used, scope (spatial and temporal), and many other factors.

5.1.1. Renewable Fuel Standard

The Energy Independence and Security Act of 2007 (EISA) specifies life-cycle GHG emissions reductions thresholds that renewable fuels must meet to qualify in different categories and defines lifecycle GHG emissions to include "significant indirect emissions such as significant emissions from land use change." As a result, EPA's analysis was conducted to capture emissions that may result from indirect land use changes in the United States and abroad. EPA's analysis of the RFS2 program was conducted estimating the effects of shocks of national aggregate demand for individual feedstocks. Partial equilibrium models of the global agricultural sector (FAPRI) and the domestic forest and agricultural sectors (FASOM-GHG) were used to simulate the effects of expanded bioenergy production consistent with RFS2 requirements on land and commodity markets. The changes in market activities and land use generated using these models were combined with emissions factors from the GREET model, satellite data analysis of modeling of land use change emissions (Harris et al., 2008), and IPCC emissions factors to generate estimates of lifecycle emissions associated with renewable fuels production.

Both direct and indirect land use changes are included in the calculation of the net lifecycle GHG reductions provided by individual biofuels feedstocks, including land use adjustments within the U.S. and internationally. Total net changes in activities are presented in that study; there is no separation of direct and indirect impacts. For a biofuel pathway to qualify under a given RFS2 category, it must meet or exceed the GHG reduction threshold for that category based on the total net emissions associated with that pathway relative to the use of fossil fuels. Renewable fuels have a minimum target of 20% reduction; advanced fuels, including biomass-based diesel, must provide at least a 50% reduction; and cellulosic fuels must reduce emissions by at least 60%.

It is also important to note that the inclusion of leakage in the RFS2 analysis is the result of fulfilling statutory obligations as set forth in the EISA of 2007. The goals, methodology, tools, and assumptions used for EPA's RFS2 analysis may not necessarily be suited for another policy analysis. Whether and how to reflect leakage in the context of a specific policy or program application of the biogenic assessment framework would need to be determined for particular applications. Each analysis must design a framework that best suits their particular goals and analytical requirements. For more information on EPA's RFS2 final rulemaking and analysis, refer to the Regulatory Impact Analysis (EPA, 2010).

5.1.2. CARB Analysis

The intent of the low carbon fuel standard (LFCS) implemented in California is to reduce the GHG emissions intensity of fuels used in the state using a performance-based standard. In its rulemaking implementing the LCFS, the California Air Resources Board (CARB) noted that incomplete policy coverage could result in little change in emissions at the global level (CARB, 2009). The LCFS implemented by CARB attempts to control leakage by adopting very similar language on including indirect emissions from EISA (OAL, 2010), which should capture indirect emissions within fuel emissions intensity estimates. Under this policy, there is a GHG intensity target developed for transportation fuels based on this lifecycle assessment. Regulated parties are the transportation energy suppliers, who are allowed to trade credits, providing incentives for using fuels with lower net carbon emissions and stimulating investment in continued development of low-carbon fuels.

CARB has worked extensively with the GTAP model to assess international land use emissions within a global framework (e.g., Tyner, 2011). Changes in land use and activities estimated using this model are combined with emissions factors obtained from the GREET model to generate estimates of the net changes in GHG emissions associated with production of individual fuels. To calculate the carbon in baseline fossil fuels across their life cycle, CARB uses the Oil Production and Greenhouse Gas Estimator to calculate a value for Annual Crude Average Carbon Intensity.

5.1.3. EU RED Analysis

The EU Renewable Energy Directive (RED) mandates that 20% of all energy usage in the EU, including at least 10% of all energy in road transport fuels, must be produced from renewable sources by 2020. In addition, an amended fuel quality directive was implemented requiring that the road transport fuel mix in the EU should be at least 6% less carbon intensive than the diesel and gasoline baseline by 2020. The EU RED also states that under national biofuel support systems, "the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that made by other biofuels." This policy also specifies sustainability criteria, whereby biofuels must achieve a minimum reduction in GHG of 35% relative to fossil fuels in order to be eligible for support under EU renewable energy policies. Beginning January 1, 2017, the threshold rises to 50% reduction in GHG. Beginning January 1, 2018, any facilities starting production on or after January 1, 2017, must meet a minimum GHG reduction of 60%.

A lifecycle methodology is defined to calculate emissions from biofuels production for the purposes of calculating the net GHG reductions. The European Commission has provided default emissions factors for each biofuel production pathway that regulated entities can use for their calculations and reporting. Regulated entities also have an option to provide information about their specific production processes in order to calculate emissions that are specific to their process for use in place of the default values. The EU RED does not currently account for indirect land use change, though it does restrict production of biofuels on land that had high biodiversity status or high carbon content at any point on or after January 2008. Information about biofuel sustainability must be tracked using a mass balance chain of custody system. There have been recent proposals and considerable debate about adding specific indirect land use change emissions factors to this policy, but agreement has not yet been reached.

5.2. Treatment of Leakage in Existing Carbon Accounting Protocols

Several organizations have developed carbon accounting protocols for companies and entities looking to measure the impact of carbon reduction (i.e., offset) projects. In creating these protocols, developers have devised methods to incorporate leakage factors into their methodologies and are pragmatic attempts at best practices for use with existing carbon reduction projects. As with the literature discussion in Section 5.1, it is often difficult to determine the precise definition of leakage used in each protocol and there are not necessarily mechanisms to adjust carbon credits on the basis of leakage.

Galik, Mobley, and deB. Richter (2009) assessed seven different protocols along a number of dimensions, including leakage. Those protocols included the U.S. Department of Energy 1605(b) Technical Guidelines for Voluntary Reporting of Greenhouse Gases (Office of Policy and International Affairs, 2007); Georgia Forestry Commission (GFC) Carbon Sequestration Registry Project Protocol (Georgia Forestry Commission, 2007); Chicago Climate Exchange (CCX) Sustainably Managed Forests/Long-Lived Wood Products Protocols (Chicago Climate Exchange, 2007a, 2007b); California Climate Action Reserve (CAR) Forest Project Protocol (CAR, 2010); Voluntary Carbon Standard (VCS) Improved Forest Management Protocol (VCS, 2007a, 2007b); a protocol based on recommended concepts in Duke University's *Harnessing Farms and Forests in the Low-Carbon Economy* (HFF) publication; and a draft recommendation for active forest management offset projects proposed by the Maine Forest Service and others under RGGI (Maine Forest Service et al., 2008). They found that only the VCS and HFF accounting standards had quantified mechanisms for accounting for leakage at the time they conducted the assessment. Both VCS and HFF included all forest carbon pools assessed by Galik, Mobley, and deB. Richter (2009) and VCS generated values for leakage between 10 to 40% (with a base case of 10%) while HFF included leakage of 33.5 to 44.5% (base case of 43%).

In addition, there are accounting procedures developed by the UNFCCC Clean Development Mechanism (CDM). The CDM methodology for simplified baseline and monitoring methodologies for small scale biomass project activities (UNFCCC, 2014) identifies three potentially significant sources of emissions (>10 % of project emissions reductions) that are attributable to the project:

- Shifts of pre-project activities, including decreases in carbon stocks outside the area where the biomass is grown due to shifts in pre-project activities;
- Emissions related to the production of the biomass; and
- Competing uses for the biomass.

Those emissions may be considered project emissions if they arise from lands under the control of the project owners or sources of leakage.

CDM guidance suggests that shifts in pre-project activities are relevant where the lands would be used for other purposes (e.g., agricultural production) in the absence of the project. In cases where the land would not be used or where land use inside the project boundary does not change as a result of the project, the guidance is that leakage does not generally need to be included. That applies to extraction of biomass from existing forests, cultivation of biomass on abandoned lands, and for biomass residues or wastes because they assume the use of the residue or waste is unlikely to affect the generation of the residue or waste. For other types of biomass, the CDM guidance is to evaluate the potential displacement of activities or people using the following indicators:

- Percentage of families/households of the community involved in or affected by the project activity displaced (from within to outside of the project boundary) due to the project; and

- Percentage of total production of the main product (e.g., corn, beef) within the project boundary displaced due to the generation of renewable biomass.

If the values of these two indictors are both less than 10%, then leakage is assumed to be 0%. If the value of either indicator is >10% but <50%, then leakage is assumed to be equal to 15% of the difference between baseline and project emissions. If the value of either is >50%, then this simplified methodology is not applicable and a new procedure must be submitted for approval.

In terms of emissions from the production of biomass, the two categories of emission included are emissions from fertilizer application and project emissions from land clearing. It is assumed that all other emissions sources are likely to be smaller than 10% individually and therefore do not need to be included. The guidance suggests that land use change other than deforestation does not need to be included and the guidance indicates that the project developers should demonstrate the area where the biomass is grown is not a forest and has not been deforested within the last 10 years.

For competing uses of biomass, the guidance suggests evaluating if there is a surplus of biomass in the region of the project activity that is not currently utilized. If it is demonstrated (e.g., based on published literature, official reports) at the beginning of each crediting period that the quantity of available biomass in the region (e.g., 50 km radius) is at least 25% greater than the quantity of biomass utilized including the project activity, then this source of leakage can be assumed to be 0%. Otherwise, leakage should be estimated and deducted from project emissions reductions,

The recently updated Climate Action Reserve (CAR) protocol (Version 3.2.) uses default leakage factors to account for changes in activities outside the project boundary. They define a decision tree for project developers to use to determine the appropriate leakage factor. A standard discount of 24% is used for cropland converted to forest (CAR, 2010; Henders and Ostwald, 2012). For other land uses, leakage is defined as 0% for improved forest management projects on actively managed forestland for projects that increase harvesting. Improved forest management projects that result in reduced harvesting relative to the baseline are assumed to have a leakage rate of 20% of the difference in harvest volume. When land had been actively grazed, the leakage factor ranges from 10 to 50% as expected canopy cover under the project increases once canopy cover reaches 30% (canopy cover less than 30% is assumed to have 0% leakage).

The updated VCS approach (Version 3.4, VCS, 2013) states that the potential for leakage should be identified and that projects are encouraged to include leakage management zones as part of the project design. Leakage management zones should be used to minimize the displacement of land use activities outside the project area by maintaining the production of goods and services within areas under control of the project proponent or by addressing socio-economic factors that drive land use change. Activities to mitigate leakage and reduce deforestation and/or forest or wetland degradation are encouraged.

In calculating leakage, specific carbon pools and GHG sources do not have to be accounted for if the omitted decrease in carbon stocks or increase in GHG emissions amounts to less than 5% of the project GHG reduction. Peer-reviewed literature or the CDM afforestation/reforestation methodological tools may be used to determine whether changes in carbon stocks and emission meet this *de minimus* level. In addition, there are specific sources defined as *de minimus* (e.g., GHG emissions from removal or burning of vegetation and collection of non-renewable wood sources for fencing off the project area). The protocol also calls for methodologies used for project accounting to adjust emissions for all significant sources of leakage using verifiable assumptions. VCS requires accounting for market leakage (production shifting elsewhere to make up for reduced supply), activity-shifting leakage (agent of deforestation or degradation moves to an area outside the project boundary and continues the deforestation or degradation activities), and ecological leakage (project causes changes in GHG emissions or fluxes of GHG emissions from ecosystems that are hydrologically connected to the project area). International leakage does not need to be quantified under this protocol. In addition, projects cannot include positive leakage where net GHG emissions outside the project area are reduced.

6. Summary

The manner in which leakage is calculated or incorporated for a particular policy, program, or study will be highly dependent on the analytical requirements of the project, the assessment scope, the feedstock(s) under consideration, and the methodology developed to carry out such an analysis. A national or global analysis of changes in feedstock demand and related commodity market and land use activities could generate estimates of the potential directionality and magnitude of leakage effects due to changes in biogenic feedstock use. However, application of the framework in this way may not be required for certain U.S. domestic policy analyses. Therefore, because this framework is intended to be policy neutral, it does not prescribe a particular leakage estimation method. For any potential application of the framework that aims to incorporate impacts from leakage, many important factors must be considered, as discussed in this appendix and shown in the examples above.

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