ALBEDO EFFECTS OF BIOMASS PRODUCTION: A REVIEW

Report to the IEA-Bioenergy Task 43 & Task 38

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Report to the IEA-Bioenergy Task 43 & Task 38

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2. ABSTRACT

Surface albedo, the fraction of reflected to total incoming solar radiation at the surface, is a property that may be affected by activities related to the extraction or production of biomass. The amplitude of surface albedo changes, and the radiative forcing generated by such changes, may be important relative to other radiative forcing components linked to bioenergy production, with potential positive or negative effects on the net climate footprint of bioenergy. This report presents an overview of the drivers of albedo, reviews measured albedo changes linked to vegetation changes or to bioenergy production systems, and reports on studies that have calculated the relative contribution of change in albedo to the overall radiative forcing of bioenergy projects. The main conclusion is that albedo-driven radiative forcing can have a substantial positive or negative impact, and its determination must be carried out on a case-by-case basis. Further, the analysis must be carried out using an appropriate metric to properly represent the time dynamics of surface albedo in biomass systems.

3. INTRODUCTION

The earth system (the Earth itself and its atmosphere) gets nearly all of its energy from incoming solar radiation (ca. 250 – 2500 nm). The proportion of the solar energy flux retained depends on two general properties: the reflectance of the earth system (as seen from space, therefore including clouds, gases, and aerosols), and the opacity of the atmosphere to out-going thermal radiation emitted by all matter heated by the incoming solar radiation. The first is referred to as albedo, a unitless property expressed as a fraction of reflected to incoming solar radiation, while the second is the greenhouse effect. Changes in either of those two properties will result in changes in the Earth's climate. Human activities have had direct influences on both.

Increasing greenhouse gas (GHG) concentrations are causing more of the sun's energy to remain trapped within the earth's atmosphere and oceans to drive the climate system. As society searches for mechanisms by which GHG emissions can be abated, renewable sources of energy are seen as an important part of the solution. One such source of energy is that obtained from burning biomass. However, the carbon density of plant material relative to fossil fuels is higher than its energy density relative to fossil fuels. As a result, at similar conversion efficiencies and not considering the GHG emissions from the extraction, transport and processing activities for biomass and fossil fuels, burning biomass emits more CO_2 than fossil fuels for the production of the same amount of energy. This extra emission is counterbalanced by the uptake of CO_2 by the vegetation for its growth, although the timing of this uptake relative to its release through combustion differs depending on the feedstock.

Humans also influence the amount of solar energy absorbed by the planet by altering its albedo[1] through activities that change the properties of land surfaces, including the management of vegetation for the production of a given bioenergy feedstock. It is within this context that the management of surface albedo, or the consideration of surface albedo in land management activities related to bioenergy feedstock production, is of interest (Schwaiger and Bird, 2010). The purpose of this report is therefore to provide an overview of the possible importance of albedo effects linked to biomass production, through the review of the current science on this topic.

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1 Basic background information on albedo and its role in the global energy budget can be found at http://esseacourses.strategies.org/module.php?module_id=99

This report deals with the albedo of land only. Albedo of water surfaces, a global concern as the arctic ice cap melts, or albedo of the atmosphere, as affected by cloud cover and altitude, are not discussed. Albedo – as a physical property – is considered part of the larger group of so-called biogeophysical properties that affect climate through their influences on heat and moisture budgets on land and in the atmosphere. Other mechanisms in this group include aerodynamic roughness, which promotes the turbulent mixing of air, sensible heat transfer, which moves energy around the atmosphere, and evapotranspiration, which transforms sensible heat into latent heat. These mechanisms are not covered in the present report but can be important for regulating local and regional climates. For example, some studies include roughness and evapotranspiration effects as part of their evaluation of local land cover conversion (Lee et al 2011, Georgescu et al 2011, Loarie et al, 2011). In addition, evapotranspiration is an important fast feedback mechanism that amplifies the climate forcing effects of increased concentrations in non-condensing greenhouse gases such as CO_2 and methane. Ultimately, however, only changes to albedo and to atmospheric concentrations of non-condensing greenhouse gases drive global climate change (Lacis et al, 2010). Nevertheless, because the local climate is what affects people and motivates climate policy, these non-radiative biogeophysical mechanisms should not be ignored in decisions surrounding land use or land management policy (Pielke et al, 2002).

4. ALBEDO, BIOENERGY, AND THE CLIMATE SYSTEM

Humans have been inadvertently modifying the earth's albedo for centuries. The widespread deforestation of the past 1000 years has increased global albedo and cooled the earth (Brovkin et al, 2006). Estimates of deforestation since 1750 coupled to measured values of albedo for different land covers suggest a global radiative forcing (RF)[2] of -0.15 ± 0.1 watts per square meter (W m^{-2}) (Ghimire et al, 2014). Likewise, desertification over the past decades has increased land surface albedo that has resulted in a large negative forcing effect (Rotenberg and Yakir, 2010). However, anthropogenic emissions of greenhouse gases since the mid-19th century have overwhelmed these effects and are now driving global warming with a current RF of about 2.29 W m^{-2} (IPCC, 2013). Local modifications of surface albedo nevertheless affect local temperatures (Lee et al, 2011; Bright et al., 2016b) as well as the earth's climate system in ways that can enhance or mitigate RF from GHG emissions.

The albedo of land is a direct land cover property and is affected by the color of the bare ground, by presence and type of vegetation, and, in cold climates, by the presence or absence of a snow cover (Stephens et al. 2015). Table 1 presents typical albedo measurements of various surface covers, arranged in order of increasing albedo values from 0.09 for a dark, closed canopy evergreen forest, to 0.71 for snow-covered grassland. The albedo of fresh snow can exceed 0.9. In general, needle-leaved conifers have a lower albedo than broad-leaved trees, and trees have a lower albedo than grasses and shrubs.

Phenology and seasonality influence albedo. The shedding of leaves by deciduous trees or shrubs exposes the ground which may be covered by a yellowing, high-albedo graminaceous plant cover in dry environments, or by snow in cold regions. Similarly, management practices also influence

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2 Radiative forcing (RF) is the difference in energy captured or lost when a change is made relative to a reference or counterfactual state, and calculated as a steady-state instantaneous value. RF is usually expressed in W m-2. The sign convention in this text is that a negative value represents a cooling effect.

albedo. For example, the short stubble left when wheat is harvested in the dry Canadian Prairie provinces captures and retains blowing snow for water conservation and ground insulation purposes, but this practice also increases snow-related albedo compared to practices that leave the ground bare in winter. For individual land cover types, the snow-free and snow-covered albedos can vary substantially across space owed to local differences in the factors described above (e.g. Gao et al, 2014). A summary of important drivers of albedo is presented in Table 2.

Reflected solar radiation is the product of albedo and the amount of incoming solar radiation. Under cloud-free conditions, incoming solar radiation varies throughout the day with changes in the sun's elevation, and across the landscape with changes in slope and aspect. Clouds may slightly change the albedo of some ground surfaces through their alteration of the spectral properties of the transmitted light. We ignore these effects in the present report as studies reviewed below report daily-integrated values from experiments carried out on generally flat terrain without any reference to overcast conditions.

The amount of energy received by the earth above the atmosphere at equatorial latitudes, also called the solar constant, is about 1.361 kW m^{-2}. Atmospheric optical properties, latitude, and day length all combine to reduce this value to a mean incoming solar radiation at the Earth's surface of 187 W m^{-2} . Because of the angle of the Earth's surface relative to the sun, incident solar radiation per unit area increases from very low values at the poles to a maximum value of 426 W m^{-2} near the equator under cloud-free conditions. All else being equal, a practice that increases albedo will therefore have a larger RF impact at the equator than at higher latitude. The high albedo of snow may however reduce such latitude-related differences. Because of all such local interactions, only a proper project-level evaluation will therefore enable the effective incorporation of albedo change RF into a bioenergy project assessment.

Across the year, daily incoming solar radiation follows a seasonal time course based on planetary mechanics in relation to the sun. Biophysical phenomena such as leaf-on and leaf-off, rainfall patterns and snow accumulation and melt also follow a seasonal time course, but in patterns that usually lag behind that of the solar cycle as a result of thermal inertia in oceanic and land masses. These lags may create critical windows of seasonal effects when albedo properties and incoming solar radiation combine in ways that sets particular practices or environments apart. For example, a snowpack that extends late in spring will dominate the albedo effect, and thus small changes in the length of snow cover season at that time of the year has a disproportionate effect on the difference in reflected solar radiation between open and closed-canopy conditions. By contrast, an early fall snow cover will have only a modest impact on the yearly total amount of reflected solar radiation because of the low solar radiation at that time of the year (e.g. Bernier et al, 2011).

Finally, the choice of metric used to evaluate the GHG mitigation potential of a given project may have a significant influence on the conclusion with respect to its climate mitigation potential, especially for time-dependent processes such as albedo. Most studies reviewed below use the concept of radiative forcing (RF) as their basic metric for reporting the warming or cooling potential of a project. RF is an instantaneous metric that has provided a useful currency for evaluating and comparing projects that deal with various kinds of climate forcings. In some studies, the albedo change RF was also translated into a CO_2-equivalent effect in order to compare directly with CO_2 and other GHG emissions or to the terrestrial carbon sinks (e.g. Betts, 2000). Importantly, however, such instantaneous metrics must be replaced by time-integrated RF metrics to properly account for differences in the temporal dynamics between forcing agents like albedo and CO_2 flux following disturbances on land. A well-known time-integrated metric is the Global Warming Potential (GWP) which normalizes the time-integrated RF from non-CO_2 forcing agents such as CH_4, N_2O, or a change in surface albedo to that of a single CO_2 emission pulse at the start of the analytical time horizon. Better alternate time-dependent measures have recently been proposed whose physical interpretation aligns more closely to measures familiar to land resource managers, like carbon changes per unit land area. In *ex-ante* analyses, for example, the Time-Dependent Emissions Equivalent (TDEE) of Bright et al (2016a) normalizes the time-dependent RF profile from albedo changes on land to a time series of CO_2 flux over the same analytical time horizon. By doing so, it creates a closer analogy to terrestrial carbon cycle dynamics in which carbon emission and sequestration fluxes are distributed over time, but also yields a CO_2-eq. value that may differ (when TDEE is summed over the analytical time horizon) from that obtained using an alternate time-integrated metric like GWP (e.g. Bright et al, 2016a).

5. BIOMASS FEEDSTOCKS AND ALBEDO

The remainder of this report is dedicated to facilitating the evaluation of albedo effects by examining the contributing factors and by providing estimates, where possible, of albedo-driven RF (or at least of changes in albedo values) for the major categories of biomass sources to be used as feedstock for bioenergy. These categories cover feedstocks extracted from various forest-based operations as well as open-field bioenergy plantations. Not considered are biomass feedstocks extracted from industrial or domestic waste streams, as their extraction will not lead to an impact on albedo. A summary of the strength of the albedo RF for the various experiments reviewed in this report is presented in Table 3.

5.1. Forest harvest residues

Harvesting operations leave behind residues in the form of tree tops, branches and foliage, and possibly downed trees from unutilized species or trees with damaged stems. The mass of harvest residues can vary from 10 to over 100 oven dry tonnes (odt) per hectare, depending on the properties of the original stand and on the harvest methods and standards (Thiffault et al, 2015). Harvest operations involve the delimbing of trees on the cut block, or the less common practice of road-side delimbing. This means that harvest residues are usually scattered on cut blocks and their removal could thus influence surface reflective properties. There does not appear to have been studies done to specifically look at the albedo changes related to this practice. However, the effect is likely negligible on account of three considerations: 1- A significant proportion of harvest residues are not recovered for technical or cost-based reasons. Thiffault et al (2015) estimate an average recovery rate of 52%, with a higher average rate of 72% for the highly managed forests of Nordic countries, but both recovery rates will lead to a relatively similar post-recovery forest floor appearance. 2- Vegetation regrowth will quickly dominate the site albedo, although this effect may vary on account of vegetation management practices and may also be influenced by the additional soil perturbation associated with residue harvest. 3- In high-latitude environments, snow usually covers the residues and further obliterates potential differences.

5.2. Disturbance wood harvest

Harvesting of disturbance wood, that is, of trees killed by natural disturbances, is a practice that has been contributing to the large pellet exports from Canada, over 1.6 M odt in 2014, mostly to the UK over the last decade. This feedstock was largely from British Columbia, and was at least partially sourced from the 15Mha of forests that were damaged by the Mountain pine beetle outbreak between 2002 and 2012. The harvest of standing dead trees increases snow exposure to incoming solar radiation in winter and spring resulting in a higher albedo. Compared to the reference scenario of no salvage logging, this practice should generate a negative RF (cooling), but the effect would be modest and short-lasting because of the modest shading effect of standing leafless trees, and because of the observed and generally fast recovery of vegetation observed for beetle-killed stands (Brown et al, 2012) . No specific study appears to have been carried out on this effect.

5.3. Conventional tree harvest

Calculations based on GHG fluxes alone suggest that using feedstock from conventional tree harvest may not yield a climate benefit for many decades if the carbon in that feedstock is not considered inherently carbon-neutral and if, as a result, calculations include the net carbon fluxes related to decomposition and regrowth between the harvest site and the atmosphere (McKechnie et al, 2011; Helin et al, 2013; Bernier et al, 2013). However, results from a Norwegian case study on electricity generation using feedstock from conventional harvest that considered carbon in trees as non-carbon neutral concludes that the inclusion of albedo-driven RF yields a reduction of global warming impact when compared to electricity from the standard European Union energy mix (Singh et al, 2014). Also in Norway, albedo RF may give live tree harvest feedstock a lower global warming potential than natural gas for district heating (Cherubini et al, 2012). The high albedo of snow is key in both of these climate-positive performances of harvested trees as bioenergy feedstock. As a corollary, this suggests that, in snow-free climates, increased albedo linked to whole tree harvest of forests not initially planted for bioenergy may be insufficient to yield climate change benefits (e.g. Caiazzo et al, 2014).

5.4. Forest conversions

Biomass can also be produced through the conversion of slower-growing natural forests to some form of fast-growing woody plantation. In that case, the effect on albedo could be permanent if the converted landscape is maintained in this new land cover in perpetuity. The sign and magnitude of the resulting RF will depend on the albedo of the plantation and of the reference vegetation in interaction with the yearly cycle of incoming solar radiation, and possibly the presence of snow.

For example, observations from North America suggest that the local RF for a conversion of evergreen conifers to broad-leaved deciduous trees would have a cooling effect of about -4.18 W m^{-2} (Zhao and Jackson, 2014). Likewise, simulations of an inverse conversion from deciduous *Larix* to evergreen *Picea* stands in southern Siberia would generate a local warming RF of 5.1±2.6 W m^{-2} (Shuman et al, 2011). In general, at high latitudes, studies of conifer forest conversion to grasslands or lichen woodlands suggest an important albedo-driven RF whose cooling effect could be equivalent to or greater than the warming effect of CO_2 emissions from the carbon in the trees being eliminated (Betts, 2000; Bernier et al, 2011). Measurements over recently burned boreal forests show albedo-induced RF values of -4.1 W m^{-2} (Jin et al, 2012), supporting the results of Zhao and Jackson, (2014) on the conversion of conifer to deciduous forests.

5.5. Open-field plantations of woody or herbaceous perennials

Industrial-scale biomass production is often envisaged as taking place on agricultural lands, whether abandoned, marginal or productive, and many research projects have been carried out for testing the environmental, technological, societal and economic appropriateness of various forms of biomass cropping systems. At the same time, afforestation research has pursued a similar logic of planting trees on deforested areas but with the end goal to support a variety of ecosystem-level benefits, including carbon sequestration, rather than fossil fuel substitution. In both cases, studies have sometimes included the albedo effect as part of their RF calculations.

Planting perennial plants, and trees in particular, on agricultural lands is estimated to have a net cooling effect in tropical regions, because of the increase in standing C stocks, but the same practice could have only a marginal site-level climate impact at high latitudes because of the lower albedo of plants as compared to snow (Bala et al, 2007; Arora and Montenegro, 2011). Calculations for birch expansion in alpine areas yielded a strong warming RF on account of the lower albedo of the bare-branched deciduous tree cover as compared to open snow fields (de Wit et al, 2014). In a similar logic, the modelling of conifer-to-deciduous forest conversion suggests that the increased snow exposure generates a cooling RF (Bright et al. 2014). However, results from two high-latitude multi-year experiments of open-field hybrid poplar plantations in Canada suggest that albedo decreases following afforestation may be overestimated in modelling studies, and that the balance between decreasing albedo and increasing standing C stock could be climate neutral or yield a small site-level cooling effect in high-latitude projects (Cai et al, 2011; Jassal et al, 2013).

The conversion of annual food crops to graminaceous perennials such as switchgrass (*Panicum virgatum*) or miscanthus (*Miscanthus* × *giganteus*) is different from a conversion to a woody feedstock such as hybrid poplar or willow in that graminaceous plants are generally (but not always) harvested in the fall. As a result, under cold climates, the wintertime albedo will likely be only moderately affected, depending on snowpack thickness and duration, and differences in blowing snow retention between the bioenergy feedstock crop and the reference crop. RF of the bioenergy crop as compared to a reference row crop will therefore depend on the seasonal changes in the properties of the bioenergy and row crops, changes in the ground conditions (i.e. with and without snow), and on the interaction between such changes and seasonal incoming solar radiation.

In a unique 5-year field study carried out in the Midwest U.S, Miller et al (2015) showed that growing season albedo was higher for both perennial switchgrass and *Miscanthus* than for the row crops maize and soy. In addition, compared to the row crops, the winter albedo of fields planted with either perennial species was higher when snow was absent but much lower when snow was present. Overall, under the climate conditions of the study site, this study found an albedo driven cooling RF of about -5 W m^{-2} and -8 W m^{-2} for switchgrass and *Miscanthus* respectively, relative to maize and soy, with the effect dominated by the growing season difference.

Cultivation of short-stature vegetation using regular or slightly modified farming practices is a very attractive option for scaling bioenergy production up to industrial levels. From an albedo perspective, however, the end result cannot be generalized from a few studies. As the examples above on *Miscanthus* and switchgrass show, the net effect can only be assessed through a detailed, multi-year comparison between the bioenergy crop and the regular crop to be replaced. Any departure from the conditions reported by Miller et al (2015) for their study may yield different values of RF for the bioenergy feedstock production.

6. BIOENERGY CASE STUDIES: RELATIVE IMPORTANCE OF ALBEDO

In bioenergy projects, the relative importance of the albedo-driven RF to the overall project-level RF depends on: 1) the type of land cover change, and hence the temporal dynamics of an albedo perturbation relative to a biogeochemical perturbation, and 2) the life-cycle GHG balance of the entire bioenergy product system (or the emission generated over the bioenergy product's life-cycle). In the biomass production system, the albedo RF will strongly depend on the permanency of any land use or land cover change. For instance, the conversion of a forest to a cropland will result in a permanent albedo change, whereas the clear-felling and subsequent regeneration of a forest will result in only a temporary albedo change. When accumulated over several decades, the difference in RF between these two cases can be substantial (Bright 2015; Bright et al, 2016). In the temporary case (i.e., the clear-felling of a forested stand) the albedo change and carbon cycle dynamics often operate on different time scales, and management actions such as those that shorten rotation lengths may be used to enhance the contribution of the albedo RF relative to the carbon cycle RF (Thompson et al. 2009).

The life-cycle GHG emissions that occur outside the land system are also important in shaping the relative contribution of the albedo RF to the total project RF. These include the economy-wide emissions linked to the production of materials and energy required as inputs (both direct and indirect) to the bioenergy system. Relative albedo RF contributions decrease with increasing fossil fuel intensity linked to the transportation, production, and distribution of biomass feedstocks and their bioenergy products. Both carbon sink and albedo change RFs connected to biomass production decrease as energy conversion efficiencies increase in the combined land use-bioenergy system (Creutzig et al. 2015).

Caiazzo and co-authors (2014) recently assessed the albedo RF contribution to the overall RF impact in 11 bioenergy systems, all of which included land use or land cover changes. In most systems the albedo RF had a non-negligible cooling effect that was opposite in sign to that resulting from changes in the C-sink and life-cycle GHGs. In four of the 11 systems studied the albedo RF completely outweighed the C-sink and GHG RF. Three of the four systems were perennial grass systems of the mid-western USA in which switchgrass replaced corn or soy in the production of liquid transportation fuels, which is in line with results reported elsewhere for similar systems and geographic locations (Georgescu et al, 2011) (Table 3).

7. CONCLUSION

Albedo is one of only two mechanisms by which human activities have directly influenced the net energy balance of the global climate system, but this influence has been largely ignored. The renewed interest in the industrial-scale production or recovery of plant biomass as an energy feedstock brings this biogeophysical effect into focus because the choice of specific bioenergy production pathways must include an evaluation of their full impact on the climate system.

The short synthesis provided in this report highlights a few key facts with respect to albedo in the context of biomass production or recovery, many of which are summarized in Table 2. The first is that albedo changes resulting from a given bioenergy system, and ensuing RF compared to a reference baseline scenario, are a function of the local environment and of the land management practices. Local environmental factors that determine the amplitude of such changes include the presence or absence of snow and the surface properties of the soil if/when devoid of snow. Land management practices that influence the amplitude and timing of the albedo-driven RF include all choices and actions that influence canopy properties, and the dynamics of these properties over time, in both the reference system and in the alternative system for biomass production. Land cover changes (e.g. forest to bioenergy crops) versus intensification of current practices (e.g. shorter rotations of forest plantations) are two types of management practices that can differ dramatically in their impact on albedo. By itself albedo is only part of the equation and the effect on the climate system is determined by the magnitude of both the local incoming solar radiation and the albedo change. The permanence or duration of an albedo change, either at the site level or at the landscape level, and to a more local extent, the topography and cloudiness of the site, will control this effect.

Initial evaluations of greenhouse gas mitigation potential of bioenergy systems that involved land conversions did not include the effect of albedo changes (Righelato and Spracklen, 2007). Evolving knowledge and increasingly sophisticated albedo measurement from space-borne sensors now enable us to include this component into the evaluation of bioenergy (Caiazzo et al, 2014). However, the choice of metrics for quantifying the impact over time is still an evolving topic and an element that affects the final answer. Irrespective of the metric, we can nevertheless conclude from our observations that case-by-case or site-specific assessments are essential for gauging the relative importance of albedo relative to greenhouse gas emissions in bioenergy production systems.

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9. APPENDIX

Table 1. Northern latitude (30-70°N) mean snow-free and maximum albedos based on MODIS satellite retrievals for a variety of land cover types. Adapted from: Gao et al (2005). See also Table 4 in Caiazzo et al (2014).

Land cover type	**Snow-free**	**Max, with snow**
Evergreen needleleaf forests	0.09	0.24
Deciduous needleleaf forests	0.11	0.36
Deciduous broadleaf forests	0.14	N/A
Mixed forests	0.12	0.26
Open shrublands	0.18	0.70
Woody savannas	0.11	0.37
Grasslands	0.18	0.71
Croplands	0.17	0.65

Table 2. Summary of important drivers of albedo, radiative forcing from differences in albedo between a bioenergy project and a reference scenario (Δalbedo RF), and the ratio of Δalbedo RF to GHG RF in bioenergy systems.

	Drivers	**Examples**
Albedo	- Local environment - Management	- Snow (temperature); soil moisture - Biomass species; canopy structure; tillage regime
ΔAlbedo RF	- Local environment - ΔAlbedo magnitude - Topography - Latitude	- Cloudiness; aerosol optical depth - Pre- and post-disturbance albedos - Exposure to solar radiation at surface (slope, aspect, topographic shading) - Seasonal exposure to incoming solar radiation
ΔAlbedo RF/ GHG RF	- ΔAlbedo and ΔC dynamics on land in time - Life-cycle GHG emissions - Metrics for valuing ΔAlbedo	- Temporary vs. permanent LULCC and management regimes - GHG emissions connected to the production of biomass and bioenergy - Instantaneous vs. time-integrated; RF vs. CO2-equivalency

Table 3. Effect on climate of changes in albedo for various projects involving land cover change relative to a reference state. The albedo-driven RF is shown in a relative evaluation among projects and is arranged from a large cooling (---) to a large warming (+++) effect. This evaluation does not include GHG forcing.

Project	Baseline	Snow cover	Climate effect	Source
Harvest of green trees	Trees left on site	yes	---	Singh et al, 2014; Cherubini et al, 2012
Conversion of conifer to deciduous	No conversion	yes	---	Zhao and Jackson, 2014, Bright et al, 2014
Soy	Cerrado	no	--	Caiazzo et al, 2014
Soy	Rainforest	no	--	Caiazzo et al, 2014
Palm	Logged forest	no	-	Caiazzo et al, 2014
Swicthgrass, miscanthus	Corn or soy	yes	+ or -	Miller et al, 2014; Caiazzo et al, 2014
Conifer plantation / afforestation	Land left open	no	+	Bala et al, 2007; Arora and Montenegro, 2011
Deciduous plantation/afforestation	Land left open	yes	+	Cai et al, 2011; Jassal et al, 2013
Palm	Rainforest	no	+	Caiazzo et al, 2014
Salicornia	Desert	no	++	Caiazzo et al, 2014
Conifer plantation / afforestation	Land left open	yes	+++	Bala et al, 2007; Arora and Montenegro, 2011

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