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TASK 38

Greenhouse Gas Balances of Biomass and Bioenergy Systems

Technology Report

'Incorporating changes in albedo in estimating the climate mitigating benefits of bioenergy projects'

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INCORPORATING CHANGES IN ALBEDO IN ESTIMATING THE CLIMATE MITIGATING BENEFITS OF BIOENERGY PROJECTS

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INTRODUCTION

One of the main objectives of Task38 is to improve and modify the “standard methodology” for the calculation of GHG balances by incorporating new issues, topics, and technologies. The impacts of Albedo on climate change benefits of a/reforestation projects are under debate. With this paper we investigate how to incorporate the changes of albedo as a CO_2 equivalent process. A model has been developed.

The removal and storage of carbon dioxide from the atmosphere by photosynthetic sequestration as trees grow is one of the components of climate change mitigating benefits of bioenergy. For this reason, there has been interest in converting non-forest lands into short rotation forests (afforestation or reforestation) for bioenergy use. Nevertheless, planting coniferous forests as a climate mitigation measure has been questioned in areas with snow since the darkening of the surface (decrease in albedo) may contribute to radiative forcing and add to the warming. For example, Betts [1] found that the change in surface albedo by the planting of coniferous forests in areas with snow can contribute significantly to the radiative forcing. Brovkin et al [2] found that cooling due to albedo change from deforestation was of the same order of magnitude as increased radiative forcing from CO2 and solar irradiation. Bala et al [3] found that a global-scale deforestation event could have a net cooling influence on the Earth’s climate.

Matthews et al. [4] on the other hand suggest that the issue needs to be revisited with more realistic scenarios of transient land cover change. In a subsequent paper, Matthews et al. [5] suggest that carbon emissions from land cover changes (deforestation) tend to exceed the cooling that results from change in surface albedo.

In a recent paper, Bird et al [6], we develop a model to incorporate the changes in albedo in estimating the climate change mitigation benefits from land-use change projects and we agree with Matthews. The phenomenon may not be limited to coniferous forests and snow. It may apply to any land use change that causes a darkening of the earth’s surface. As a new technology, at JOANNEUM RESEARCH, we are modelling the changes in combined radiative forcing due to changes in albedo and carbon stocks over time due to a change in land-use from grasslands to various bioenergy crops at various locations. In this technology update, we present preliminary data that combined impacts of sequestration and albedo change in terms of radiative forcing and equivalent changes in CO_2.

THE MODEL

The model contains three components; a carbon model, a surface albedo model and a model to correct the surface albedo for atmospheric effects, and formulas that convert changes carbon stocks into radiative forcing and vice versa. For a full description of the model we refer you to Bird et al [6]

Carbon
To model the changes in carbon stocks over time we use the stand level carbon model GORCAM [7], that has been modified to include the non-woody biomass dynamics. It is a simple model that tracks the flow of carbon from living above and below ground biomass to the dead wood, litter and soil pools. The model assumes that the living above ground biomass is driven by local growth curves or yield tables; the below ground living biomass is a function of the above ground biomass; and that annual litter input is a fraction of the living biomass. The litter biomass decays exponentially with decay rates based on temperature, rainfall and material [8, 9]. Some of the decaying material enters the soil pool, which also decays exponentially.

Albedo
Albedo is a very complex function of surface and radiation characteristics, including land cover type, specifics of the vegetation, snow cover, soil moisture, incident angle, and wavelength [10, 11]. We use average values determined from measurements as published in a number of journals [12].

Atmosphere
The climate forcing effect of changes in surface albedo is modified by the atmosphere. The atmosphere absorbs energy. Clouds and dust and ice particles reflect and scatter the incoming solar radiation and the energy reflected by the earth's surface. As a result, the changes in surface albedo are somewhat muted by the atmosphere, see Figure 1.

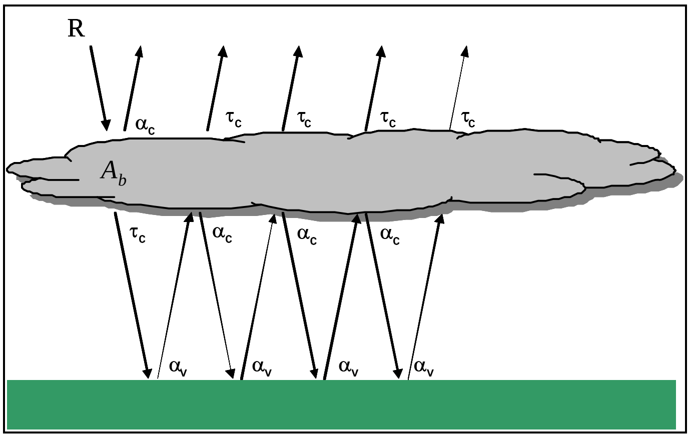

Figure 1: Schematic of cloud scattering

For this study we use the Fu-Liou Radiative Transfer Model [13].

Equivalency of changes in carbon stocks and radiative forcing
Changes in CO_2 have an equivalent radiative forcing [1] as shown by

$$F_{CO_2}^{Ann}\left[\mathrm{Wm^{-2}}\right] = \frac{\Delta F_{2X}\left[\mathrm{Wm^{-2}}\right]}{\ln(2)} \ln\left(1 + \frac{1.0 \text{ x } 10^6 [\mathrm{ppmv}] \Delta CO_2 [\mathrm{g}] M_{air} [\mathrm{gmole^{-1}}]}{pCO_{2,ref} [\mathrm{ppmv}] M_{CO_2} [\mathrm{gmole^{-1}}] 1.0 \text{ x } 10^6 m_{air} [\mathrm{Mg}]}\right)$$

Where M_{CO2}= molecular mass of carbon (44.0095 g/mol), M_{air}= molecular mass of dry air (28.95 g/mol), m_{air}= mass of the atmosphere (5.148 x 1015 Mg), ΔCO_2 = the change in CO_2 (in grams) as a result of the reforestation project and ΔF_{2X} = the radiative forcing per CO_2 doubling (3.7 $\mathrm{Wm^{-2}}$)

When the delayed absorption of CO_2 by the atmosphere is included a change in CO_2 has an equivalent radiative forcing of

$$F_{CO_2}^{Ann}(t)[\mathrm{Wm}^{-2}] \approx \frac{\Delta F_{2X}[\mathrm{Wm}^{-2}]}{\ln(2)} \left(\frac{1.0 \times 10^6 [\mathrm{ppmv}] \Delta CO_2(t)[\mathrm{g}] M_{air}[\mathrm{gmole}^{-1}]}{pCO_{2,ref}[\mathrm{ppmv}] M_{CO_2}[\mathrm{gmole}^{-1}] 1.0 \times 10^6 m_{air}[\mathrm{Mg}]} \right) \otimes Decay_{CO_2}^{Ann}(t)$$

Where $\otimes$ represents the convolution operation and $Decay_{CO_2}^{Ann}(t)$ is given by

$$\Delta CO_2 eq_\alpha(t)[\mathrm{g}] \approx \frac{F_{CO_2}^{Ann}(t)[\mathrm{Wm}^{-2}]\ln(2)}{\Delta F_{2X}[\mathrm{Wm}^{-2}]}\left(\frac{pCO_{2,ref}[\mathrm{ppmv}]M_{CO_2}[\mathrm{gmole}^{-1}]1.0\times10^6 m_{air}[\mathrm{Mg}]}{1.0\times10^6[\mathrm{ppmv}]M_{air}[\mathrm{gmole}^{-1}]}\right)\otimes InvDecay_{CO_2}^{Ann}(t)$$

A change in albedo has an equivalent CO_2 emission given by:

$$\Delta CO_2 eq_\alpha(t)[\mathrm{g}] \approx \frac{F_{CO_2}^{Ann}(t)[\mathrm{Wm}^{-2}]\ln(2)}{\Delta F_{2X}[\mathrm{Wm}^{-2}]}\left(\frac{pCO_{2,ref}[\mathrm{ppmv}]M_{CO_2}[\mathrm{gmole}^{-1}]1.0\times10^6 m_{air}[\mathrm{Mg}]}{1.0\times10^6[\mathrm{ppmv}]M_{air}[\mathrm{gmole}^{-1}]}\right)\otimes InvDecay_{CO_2}^{Ann}(t)$$

Where $InvDecay_{CO_2}^{Ann}(t)$ is the inverse-filter of $Decay_{CO_2}^{Ann}(t)$ so that

$$Decay_{CO_2}^{Ann}(t) \otimes InvDecay_{CO_2}^{Ann}(t) = 1$$

$InvDecay_{CO_2}^{Ann}(t)$ can be calculated analytically since we are modelling only changes in albedo (i.e., no change before the start of the project).

EXAMPLES

Reforestation for electrical generation in Romania

The first example comes from the Dolj area in south western Romania. Here, Robinia (Black locust) has been planted on grassland as a biomass source for electricity generation. The area has an average annual temperature of 11.3° and rainfall of 500 mm. There is snow cover greater than 5 cm depth in December, January, and February. Harvesting occurs every 30 years.

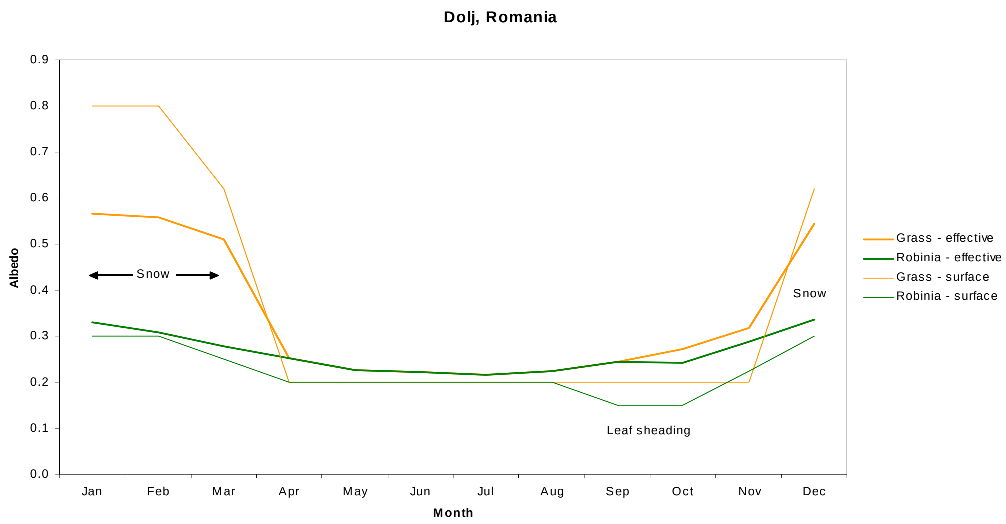

Figure 2: Change in albedo due to reforestation, Dolj Romania

The change in albedo for this example is shown in Figure 2. At year 0, only grass is present and so there is a high albedo during the months with snow cover. The cumulative emissions by year from the land-use change component are shown in Figure 3. The saw tooth pattern is caused by the harvest every 30 years. The net sequestration of carbon stocks (negative emissions) is almost completely overcome by the albedo forcing (warming) due to the darkening of the surface.

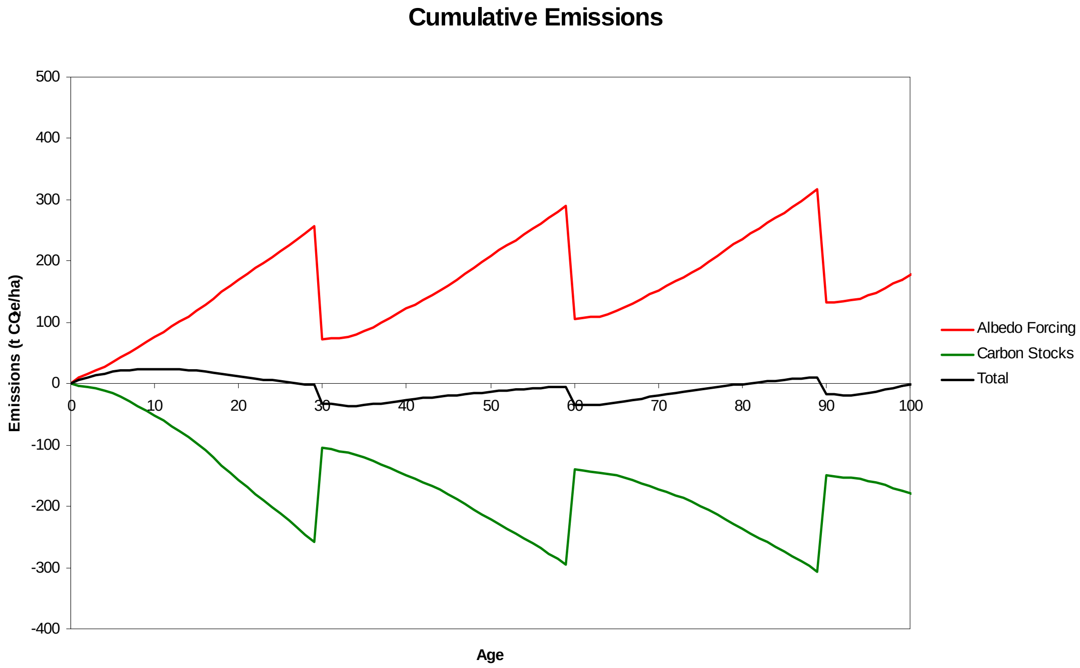

Figure 3 Cumulative emissions due to Robinia plantation, Dolj, Romania

Jatropha curcas plantation in South Africa

The second example comes from near Johannesburg, South Africa. Here Jatropha curcas has been planted on grassland as a source of oil seed for biodiesel production. The area has an average annual temperature of 16.0° and rainfall of 619 mm. During June, July and August there is less that 2.0 mm of rainfall. This drought period causes a brightening of the grassland (Figure 4). Seeds from the Jatropha are harvested after 2 years, and the plants are trimmed to a constant height of 2.0 m after 10 years.

We have assumed that the albedo for Jatropha is similar to a broadleaf tree as we have not been able to find studies on the albedo of Jatropha.. The increase in albedo (brightening) for the grasses is caused by the period of drought. The increase in albedo for the 10 year-old plantation in is a result of the Jatropha shedding its leaves.

The cumulative emissions by year from the land-use change component are shown in Figure 5. The change in albedo causes a sharp increase in equivalent emissions. The Jatropha sequesters carbon as it grows. The pruning after 10 years stops the growth and the sequestration does not fully compensate for the equivalent emissions caused by the albedo change.

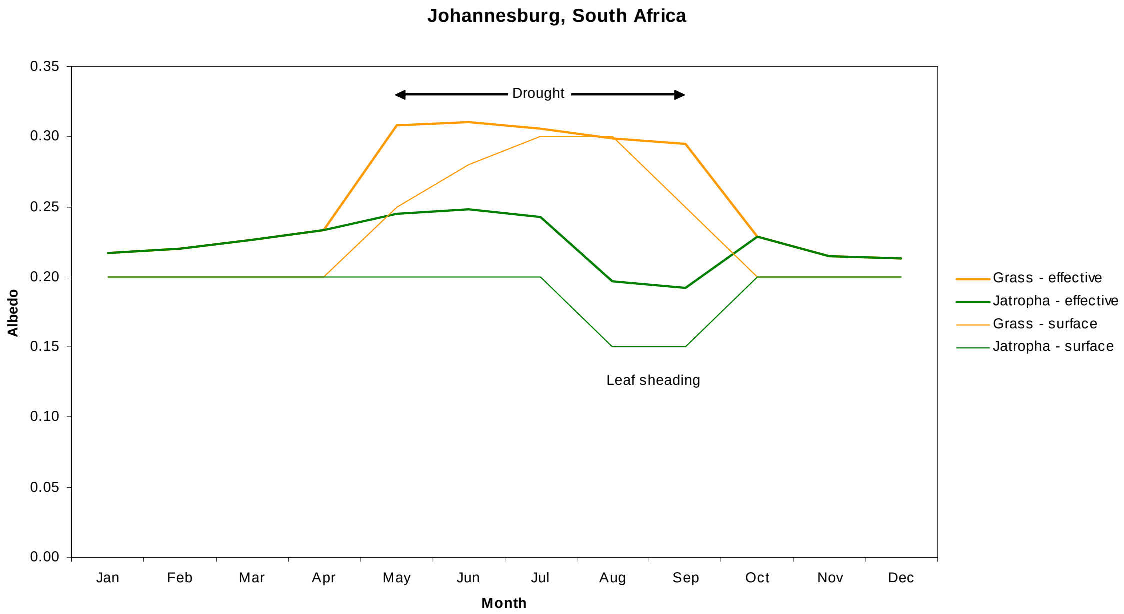

Figure 4: Change in albedo due to Jatropha curcas, Johannesburg South Africa

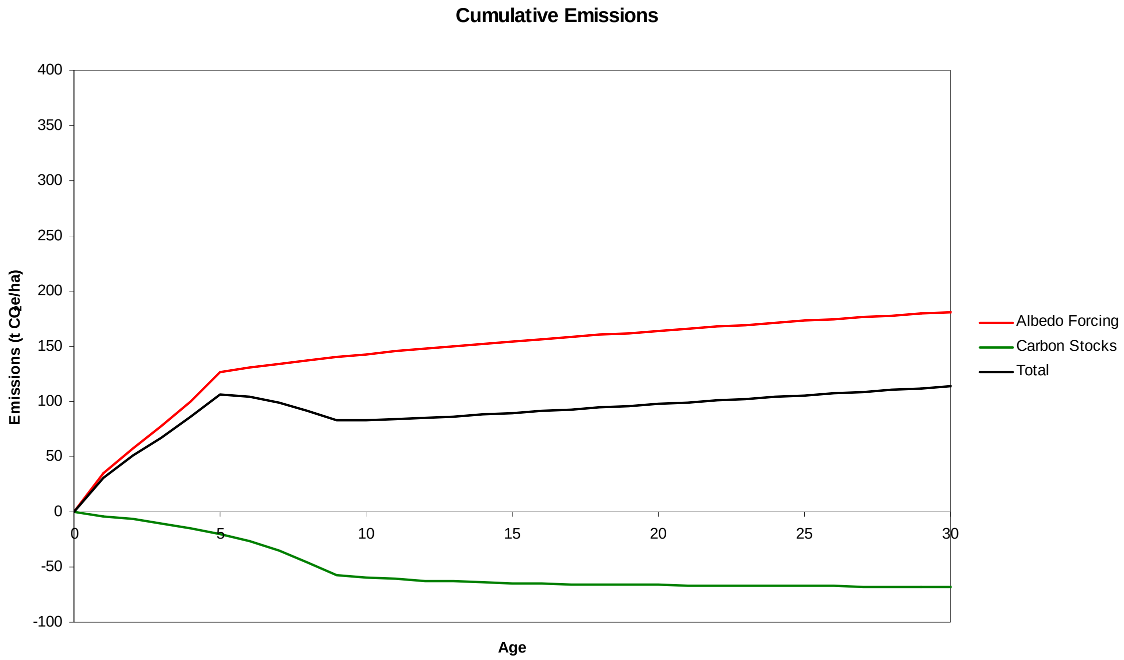

Figure 5: Cumulative emissions due to Jatropha plantation, Johannesburg South Africa

CONCLUSIONS AND RECOMMENDATIONS

Table 1 shows the GHG emissions over the first cycle during establishment of the plantations. This term is equivalent to the emissions from the construction of a factory or facility. The table shows that the emissions removals (sequestration alone) from land-use change significantly contribute to the greenhouse gas benefits from projects where the land-use change incorporates an increase in biomass. This is not a new finding but this component is often not included in LCA of bioenergy systems.

What this analysis has added is the equivalent greenhouse gas emissions caused by the change in surface albedo that also results from the land-use change. This analysis shows that the change in albedo can be a significant source of equivalent emissions than can counteract the sequestration benefit of land use change. The change in albedo is exaggerated when dark trees are planted where there is snow. It is also exaggerated where dark crops are planted in grasslands that are subject to drought. The second result raises concern about the greenhouse gas emission benefits from bioenergy crops which do not include a large accumulation of biomass.

The results should still be considered as preliminary since the albedo change is based on field measurements and a model of the atmosphere. It should be confirmed using available MODIS data. As well, the analysis does not include the energy impacts of changes in evapotranspiration that often accompanies a land-use change. Increased evapotranspiration may have a feedback effect by increasing cloud cover. Further research is required.

Table 1: GHG emissions over the first cycle

	units	Robinia, Rumania	Jatropha, South Africa
Biomass	(t/ha/yr)	3.2	1.9
Useable energy			
Diesel	(GJ/ha/yr)		71.7
Electricity	(kWh/ha/yr)	1851	
Emissions			
Combustion of biofuel	(t CO2e/ha/yr)	0.2	0.4
Maximum emissions saved from displacement of fossil fuel	(t CO2e/ha/yr)	-1.9	-5.3
Net excluding land-use change	**(t CO2e/ha/yr)**	**-1.7**	**-4.9**
Sequestration	(t CO2e/ha/yr)	-6.2	-6.4
Albedo	(t CO2e/ha/yr)	5.5	15.3
Net including land-use change	**(t CO2e/ha/yr)**	**-2.4**	**4.0**
Albedo/Sequestration		89%	240%
LUC / Energy		0.41	1.80

Positive values are emissions to atmosphere. Negative values are removals from atmosphere. Emissions from land-use change are calculated using the average cumulative emissions over the second cycle and pro-rating them over the first rotation. Electricity emissions are calculated assuming 50% efficiency replacing coal with an emission intensity of 1.0 kg CO_2/kWh.

References

1 Betts, R.A. 2000. Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. Nature 408, 187-190.

2 Brovkin V, Ganopolski A., Claussen M., Kubatzki C., and Petoukhov V. 1999. Modelling climate response to historical land cover change. Global Ecology and Biogeography 8, 509-517.

3 Bala, G., Caldeira, K., Wickett, M., Phillips, T.J., Lobell, D.B., Delire, C., and Mirin, A. 2007. Combined Climate and Carbon-Cycle Effects of Large-Scale Deforestation. PNAS 104: 6550-6555.

4 Matthews H.D., Weaver A.J., Eby M. and Meissner K.J. 2004. Radiative forcing of climate by historical land cover change. Geophys. Res. Lett. 30(2), 1055.

5 Matthews H.D., Weaver A.J., Meissner K.J., Gillett N.P. and Eby M. 2004. Natural and anthropogenic climate change: incorporating historical land cover change, vegetation dynamics and the global carbon cycle. Climate Dynamics 22, 461-479.

6 Bird D.N., Kunda M., Marland G., Mayer A., Schlamadinger B., Canella L., and Johnston M. 2008. Incorporating changes in albedo in estimating the climate mitigation benefits of land use change projects. Biogeosciences. In press.

7 Schlamadinger, B., and G. Marland. 1996, The Role of Forest and Bioenergy Strategies in the Global Carbon Cycle, Biomass and Bioenergy 10: 275-300.

8 Moore, T.R., Trofymow, J.A., Taylor, B., Prescott, C., Camire, C., Duschene, L., Fyles, J., Kozak, L., Kranabetter, M., Morrison, I., Siltanen, M., Smith, S., Titus, B., Visser, S., Wein, R., Zoltai, S. 1999. Litter decomposition rates in Canadian forests. Global Change Biology. 5: (1) 75-82.

9 Trofymow, J.A., T.R. Moore, B. Titus, C. Prescott, I. Morrison, M. Siltanen, S. Smith, J. Fyles, R. Wein, and, C. Camire, L. Duschene, L. Kozak, M. Kranabetter, S. Visser. 2002. Rates of litter decomposition over six years in Canadian forests: Influence of litter quality and climate. Can. Jour. For. Res.. 32: 789-804.

10 Henderson-Sellers, A. and Wilson, M.F. 1983. Albedo Observations of the Earth's Surface for Climate Research. Phil. Trans. Roy. Soc. of London, 309/1508, 285-294.

11 Ni, W. and Woodcock, C.E. 1999. Surface Albedo of Boreal Conifer Forests: Modeling and Measurements. Geoscience and Remote Sensing Symposium, 1999. IGARSS '99 Proceedings. IEEE.

12 Pielke, R.A. and Avissar, R. 1990. Influence of landscape structure on local and regional climate. Landscape Ecology 4, 133-155.

13 http://snowdog.larc.nasa.gov/cgi-bin/rose/flp200503/flp200503.cgi