

BIOENERGY: THE RELATIONSHIP WITH GREENHOUSE GASES IN AGRICULTURE AND FORESTRY

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ABSTRACT: The main interest in bioenergy as a climate change mitigation strategy is that it is considered to be a CO₂ neutral energy source. This is based on the argument that the same amount of CO₂ is released at the point of use as has been removed from the atmosphere via the process of photosynthesis. In practice, biomass energy is not always from renewable sources. The production of biomass may result in decreases of carbon stocks in above ground biomass, below ground biomass, dead wood, litter and soil. One should include the associated CO₂ emissions from the losses in these carbon stocks. The paper focuses on the three main aspects of bioenergy and land-use: 1) The GHG balance is not only influenced by direct emissions from land use, but also by the indirect emissions caused by displacement of other land uses. 2) There are trade-offs between growing biomass crops and displacing fossil fuels, or storing carbon. Modelling suggests that bioenergy production is superior if biomass, from high-yielding plantations, is produced efficiently, displaces GHG-intensive fossil energy, and a long-term view is taken. 3) To date there are few CDM methodologies for biofuels because of the impact of bioenergy on the availability of land. While the CDM focuses on the effects of individual projects, the land use issues discussed in this paper can hardly be attributed to a single activity but tend to be the result of macroeconomic developments.

Keywords: greenhouse gases (GHG), land use, Clean Development Mechanism (CDM)

1 WHEN IS ENERGY FROM BIOMASS RENEWABLE?

The main interest in bioenergy as a climate change mitigation strategy is that it is considered to be a CO₂ neutral energy source, if the bioenergy is sustainably produced (i.e. from a renewable biomass source). This is based on the argument that the same amount of CO₂ is released at the point of use as has been removed from the atmosphere via the process of photosynthesis (Figure 1).

In countries with a national greenhouse gas emission target (Annex-I countries of the UNFCCC), it is assumed that sustainable agricultural and forestry practices are in effect. If they are not, any loss of biomass, particularly deforestation or land degradation, is captured in the land-use part of the national greenhouse-gas inventory. As a result, all bioenergy use is considered CO₂ neutral in the energy sector of national inventories of greenhouse gas emissions.

In countries without national greenhouse gas emission targets (non-Annex I countries or developing countries), the assumption of sustainable agricultural and forestry practice is not made and the renewable nature of the biomass for energy use must be demonstrated. This has been a significant stumbling block for acceptance of methodologies for biofuel projects under the Clean Development Mechanism (CDM). Net CO₂ emissions from the use of biomass can only be ignored if biomass is renewable [1]. Under the CDM, biomass is defined as renewable if [2];

1. There is no change in land-use, or the land-use change is from cropland or grassland to forest (i.e., afforestation or reforestation); and
2. There are sustainable management practices in effect to ensure that there is no systematic decrease in carbon stocks on the land [3]; and
3. The practice is in compliance with all national and regional forestry, agriculture and environmental regulations.

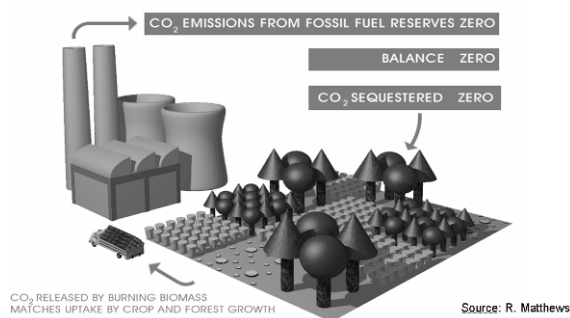


Figure 1: Closed carbon cycle associated with biomass use for energy

Residual biomass from agricultural or forestry operations is also considered renewable if the use of the residues does not cause a decrease in carbon stocks on the land where the biomass originated.

In practice, biomass energy is not always from renewable sources. Land management associated with production of biomass may result in decreases of carbon stocks in the five relevant carbon pools (above ground biomass, below ground biomass, dead wood, litter and soil). For example, the production of biofuels from palm oil plantations is not renewable if the land was deforested to enable the establishment of the palm oil plantation. Similarly, retrieving biomass may result in the decrease of dead wood, litter or soil carbon stocks. For example, a project that increases the collection of dead wood in an existing forest would not be considered "renewable" if this practice depletes the carbon pool of dead wood in the forest. Another example would concern the planting of an annually tilled bioenergy crop, such as rape seed, on grassland. The annual tillage of the soil due to the bioenergy crop could cause a systematic decrease in the soil carbon stocks and as a result the practice would not be considered "renewable". If the bioenergy system is not "renewable", then one should include the associated CO₂ emissions from land use in the calculation of net greenhouse gas emission benefits.

On the other hand, there are bioenergy production schemes that may at the same time increase terrestrial carbon stocks. For example, afforestation, reforestation or revegetation may enhance carbon stocks in plants and soils, while at the same time contributing to a future biomass resource that will be needed if emissions continue to be reduced, and greater shares of renewable energy are desired. Bioenergy helps overcome saturation constraints of such reforestation activities, and helps address non-permanence. Incentives for carbon-stock enhancing activities are needed to build the resource for modern biomass energy and to reduce pressure on existing forests. In the long term, bioenergy will only be CO₂ neutral if there are also policies to enhance photosynthesis by the same amount as the use of biomass is increased. Simply increasing the use of biomass may lead to net depletion of C stocks (see “non-renewable biomass” section above), and may even lead to deforestation, degradation and de-vegetation.

Conversely, the use of land for producing biomass fuels may reduce the ability of the land to store more carbon, as is discussed in the following section.

2 SHOULD SURPLUS AGRICULTURAL LAND BE USED FOR BIOENERGY PRODUCTION OR CARBON SEQUESTRATION?

A recent article[4] has argued that forestation of land would sequester two to nine times more carbon over a 30-year period than the emissions avoided by the use of biofuel grown on the same land. The article continues to say that only the conversion of woody biomass may be compatible with retention of forest carbon stocks, and avoided emissions may be similar to carbon assimilation by forest restoration.

Figure 2 shows the results of modelling where the relative merits of using land for bioenergy production has been compared with use of the land for carbon sequestration. The results are dependent on:

- Efficiency with which biomass energy can substitute for fossil fuel energy. This efficiency is high if:
 - Biomass is produced and converted efficiently;
 - The replaced fossil fuel would have been used with low efficiency; and
 - A carbon intensive fossil fuel is replaced.
- Time period of consideration: the longer the timeframe of the analysis, the more attractive biomass energy is in comparison with carbon sequestration, because the latter is constrained by saturation (only a limited certain amount of carbon can be stored on a hectare of land), whereas bioenergy can be produced repeatedly, from harvest cycle to harvest cycle.
- Growth rate of the site. The higher the growth rate, the sooner the saturation constraints of carbon sequestration will be reached.

Figure 2 shows that a combination of high yielding species and efficient use of the biomass to replace fossil fuel makes substitution management the preferable option over sequestration management. In the back right corner of the diagram the benefits of substitution management exceed those of sequestration management by almost 250 tons carbon / ha after 40 years. On the other hand, low-efficiency biomass use, independent of growth rate, means that the land is better used for carbon sequestration. Where biomass is used efficiently, but

growth rates are low, the relative merits of substitution management are limited.

3 SHOULD EXISTING FORESTS BE HARVESTED FOR TIMBER AND BIOMASS FUELS, OR BETTER BE PRESERVED TO STORE CARBON?

So far the discussion has focused on the best use of non forested land. In other cases the decision is about whether existing forests should be utilized for bioenergy and timber production, or protected for maximum carbon storage. This discussion also applies where biofuels production, through leakage, leads to losses or degradation of existing forests.

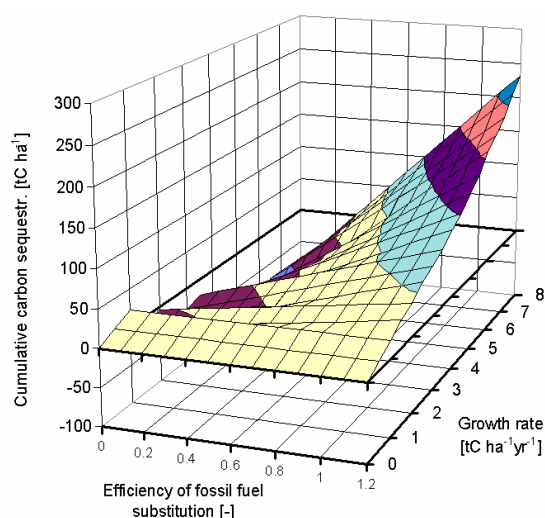


Figure 2: The difference after 40 years between a scenario where land is reforested with fast growing species to produce biomass energy, and a scenario where land is reforested with the main purpose of storing carbon. The coloured surface (vertical axis) depicts cumulative carbon benefits of substitution over sequestration as a function of the efficiency of bioenergy use, and the growth rate. Positive values indicate that management for biomass energy is the better choice [5].

Similar to the preceding section, modelling results demonstrate that substitution management yield greater benefits if⁵

- Initial carbon stocks in the forest are low;
- Growth rates are high;
- Biomass is used efficiently; and
- A long-term view is taken.

4 WHAT ARE THE DIRECT AND INDIRECT EMISSIONS FROM BIOENERGY PRODUCTION?

4.1 Direct emissions

Direct emissions comprise, among others, the emissions from energy used during production, transport of the biomass, construction of the facility used for biomass conversion and energy used during the conversion process. While there are upstream emissions involved in every CDM project activity these are

generally not considered of huge impact and have hardly impacted the approval of a methodology [6].

The situation is different when it comes to bioenergy projects. Here, emissions associated with the land preparation prior to the planting of an energy crop can be substantial, particularly if the cultivated land had previously been forested. This is analogous to the construction of a facility in an energy system. The emissions from the clearing of vegetation are predominantly CO₂ from the loss of biomass, but may include CH₄ and N₂O emissions if the vegetation is burnt during clearing.

Emissions also occur during the production of the biomass from the application of synthetic and natural fertilizers and the use of fossil fuels during the cultivation and harvesting of the bioenergy crop. This is analogous to the operating of the factory in an energy system

The CDM Methodological Panel has released a tool to estimate these emissions [7]. This tool includes all direct emissions from land-use with the exception of losses of carbon stocks from deadwood and litter other than in plantation establishment.

4.2 Indirect emissions

Indirect emissions, generally termed "leakage", are those emissions that occur outside the project boundary as a result of biomass production for bioenergy. These come from three main sources: the consumption of fossil fuels outside the project boundary during establishment and management of the bioenergy system, the production of fossil fuels, fertilizers or other soil additives used during cultivation; and the displacement of land-use activities.

The first two tend to be small components of total project emissions and are covered by a tool developed by the CDM Methodologies Panel [8]. The latter, emissions that result from the displacement of the land-use activities are more significant and is the primary concern of non-governmental organizations (NGOs).

To examine the significance of the displacement of activities let us consider a typical *Jatropha* plantation that produces 1 ton oil/ha/year and results in the reduction of emissions from diesel of approximately 3 t CO₂e/ha/year. If this plantation causes a shift in land-use practices that causes deforestation of 20% of the area used for biomass production, and assuming a loss of 300 t CO₂e/ha, then there is no net greenhouse gas mitigation benefit for 20 years, even in absence of any emissions from processing the bio-oil into diesel fuel.

Deforestation is an extreme example, but emissions can occur from nearly any displacement of agricultural activities. For example, if a biomass plantation causes an area of land that was grassland to be cultivated or grazed then there is possibly a loss of soil carbon. The resulting emissions could be as high as 45 t CO₂e/ha [9]. Consequently, there is no net greenhouse gas emission benefit for 15 years.

The CDM Methodological Panel Tool assumes that emissions from displacement of land-use can be ignored if the project is implemented after 31 December 2006 and if the land area of biomass production has not been a forest since that time. The project proponents must document the land-use over the 10 years prior to the start of the project. The Tool does not address other displacement of land-use but the project proponents need to include methodological approaches that take this into account.

5 HOW DO BIOFUELS IMPACT AGRICULTURAL MARKETS AND LAND USE?

The two most important liquid biofuels today are ethanol and biodiesel. Ethanol is produced from sugars and starches contained in a wide variety of crops, primarily from sugar cane (in Brazil) and corn (in the U.S.). Biodiesel is primarily produced from vegetable oil contained in a wide variety of crops, primarily from rapeseed (Germany), soy (U.S. and Brazil), and oil palm (Indonesia and Malaysia).

The advantages of biofuels most often cited include independence from insecure energy supplies, promotion of rural development, reduced local air pollution and, last but not least, development of a new climate-friendly source of energy.

Despite significant investment and government support for biofuels, ethanol, represented a mere 1.2% of global gasoline supply in 2005. However, while biofuels have only a marginal impact on the gasoline market, they have a significant impact on the price of agricultural crops. For example, in 2006, ethanol represented about 3.5 percent of gasoline supplies in the United States. However, about 20 percent of the corn from the 2006 crop year went to ethanol production. By 2010, the U.S. Department of Agriculture estimates that more than 30 percent of the U.S. corn crop will be used to produce ethanol. The growing significance of biofuels to the agricultural markets has a number of implications to agricultural prices and land use.

First, the prices of many agricultural crops are increasingly determined by the price of their energy equivalent. With increasing demand for crude oil, lead by demand in developing countries such as China and India, many market observers believe that the price of crude oil and thus the price of biofuel crops are likely to continue to rise.

Second, as biofuel crop prices rise, the prices of other agricultural commodities will follow since they are highly correlated to biofuel crop prices because cropland can be used to produce different commodities. Many commodities are substitutes in consumption. Agricultural commodities are internationally traded and have a single price after allowing for transportation and quality differences. For example, higher corn prices encourage farmers to increase corn acreage. Since cropland used for soybeans can also be used for corn, soybean acreage shifts to corn production. Reduced production of soybeans, along with increased demand for soybean oil from biodiesel, leads to higher soybean prices. The prices of other vegetable oils that can be substituted for soybean oil will also increase, while the prices of other grains, such as wheat, that are used as feedstock replacements for corn, will also rise. Meat and dairy prices are also affected, as higher feedstock costs must be recovered.

Third, rising agricultural prices driven by biofuel production provide incentives to convert more land to agricultural production. In some instances, additional cropland comes at the expense of carbon dense forests, resulting in significant emissions from the conversion of land for biofuel crops. Expansion of soybean production in Brazil, and palm oil production in Malaysia and Indonesia, are cases in point. In other instances, additional cropland comes from less carbon dense lands but shifting of pre-existing activities from those lands to forested lands can lead to significant emissions. For

example, the expansion of sugar production in Brazil has come largely at the expense of pasture. This leads to worries that the grazing of cattle, with beef being another booming export product, could be shifted to the Amazon and result in greater deforestation.

For policymakers, the linkage between land use and biofuels has important implications. First, biofuels even if produced domestically on existing cropland, can result in land use emissions elsewhere due to price impacts on other agricultural commodities caused by substitution effects and international markets. Second, the climate change benefits of biofuels, as measured on a lifecycle basis, must be evaluated against land use emissions resulting directly or indirectly from bringing in new land into agricultural production. Third, efforts to curb deforestation must recognize that the opportunity cost of forest land is influenced by the price of oil and government subsidies for biofuel as translated into agricultural commodity prices.

6 ARE THERE OTHER CLIMATE CHANGE EFFECTS INVOLVED?

Finally, there is another potential climate change effect related to changes in land use. By changing surface albedo from light land to darker land cover, the project may increase global radiative forcing and thus cause local warming. This has been considered a problem by some authors for afforestation and reforestation projects using conifers in northern climates with snow. But it may turn out to be less of an effect as thought due to the presence of clouds.

This may not be the case for bioenergy plantations, particularly *Jatropha*, which are planted on marginal lands in sunny tropical lands. The marginal lands will be light coloured while the bioenergy plantation will be darker and the change in surface albedo will not be muted by the presence of clouds.

Another important consideration is the flux of latent heat due to the increased evapotranspiration, which has a local cooling effect. Modelling of albedo and latent heat fluxes is still in its infancy, and will need to be improved before being able to take this into account in climate-change mitigation policies.

7 BIOMASS AND LIQUID BIOFUELS IN THE CLEAN DEVELOPMENT MECHANISM

To date, the massive growth in biofuel investment in recent years has had no correspondence under the Clean Development Mechanism (CDM), a trading framework that allows emission-reducing projects in developing countries to earn and sell carbon credits. So far, not a single biofuel project activity has been successfully registered. That is astonishing for a category that by public and experts' accounts alike is one of the key technologies for reducing the emissions from transportation.

The obvious barrier with regard to the CDM is the lack of approved methodologies. Two issues in particular are holding up the development of methodologies for this asset class: the treatment of indirect emissions and concerns of double counting – both the consumer and the producer claiming the emission reductions. These issues

are by no means unique to biofuel projects; however, they are particularly relevant in a biofuel context.

To date, the CDM Executive Board (EB) has approved only one methodology for biofuel projects and has rejected all other submissions. The approved methodology, AM0047, is limited to projects using waste cooking oil as feedstock and supplying biodiesel directly to the end-user. By restricting the scope of application, the methodology avoids the concerns of indirect emissions and double counting, however at the price of ruling out most biofuel projects.

As already discussed, indirect emissions arise in the production of an energy resource or commodity. While these are involved in every CDM project activity these are generally not considered of huge impact and have hardly impacted the approval of a methodology [10]. The situation is different when it comes to bioenergy projects. Here, emissions associated with the displacement of agriculture by an energy crop are considered substantial. Bioenergy projects that have become registered under the CDM rely almost exclusively on waste biomass that is not specifically planted for the purpose of energy generation.

While it appears cumbersome but feasible to account for the direct emissions from the use of fertiliser and agricultural machinery during production of biomass for energy, estimating the effect of establishment of the biomass crop on deforestation and the loss of sequestered carbon is infinitely more complex. The latter is referred to in the discussion as “shift in pre-project activities”. Two approaches are currently under discussion:

- Managed leakage approach: estimating the net decrease in above and below ground carbon from cultivating renewable biomass on a dedicated land area, and
- Regional approach: developing regional default factors to capture deforestation trends in different regions

The difficulty with using a managed leakage approach is that often the displaced activity moves to a site which itself had a different activity. As a result, the deforestation effects are not easily attributable to a specific project. Even if feedstock is supplied from an existing plantation, the increase in demand may be met through the establishment of a new plantation elsewhere. Regional approaches, on the other hand, may be better suited to capture macroeconomic trends but do not allow to distinguish individual land management practices.

There are possible solutions to the dilemma;

1. As we have seen, projects could be restricted to those that use waste biomass thus limiting the likelihood of activity displacement causing deforestation or cultivation of grasslands;
2. Projects could be limited to cultivations that are established on degraded or waste land where no competing use is crowded out [11] Biofuel plantations established on wasteland, as for instance *Jatropha* cultivations, may thus well be the first category to succeed under the CDM;
3. Emission reductions generated by CDM projects are discounted by the deforestation rate in the host country
4. A prerequisite for the creation of tradable emission reductions from biofuels could be that the host country adopts a target for reducing emissions from deforestation and degradation post-2012

The methodologies that are now being developed for addressing biomass sustainability in the CDM may also show the way for addressing this concern more broadly for biomass fuels that are used locally or traded between countries. Certification schemes, taking into account experiences from existing forest certification approaches (e.g., Forest Stewardship Council), combined with the experience gained in the CDM, could be critical for ensuring that global biomass is effective in reducing greenhouse-gas emissions.

8 CONCLUSIONS

This paper has discussed the relationship with greenhouse gases in agriculture and forestry in bioenergy production. We have shown that bioenergy production can be considered CO₂ neutral if the conditions of no systematic decrease in carbon stocks in all five pools (above-ground and below-ground live biomass, litter, dead wood and soil) are met. Otherwise the emissions caused by the loss of carbon stocks should be considered. In reality, there are no changes in carbon stocks only if the system is not in still in the state of transition that resulted from a recent change in land-use. Emissions from the transformation of land-use must always be considered when evaluating bioenergy options.

We have described what direct and indirect emissions are associated with bioenergy production. Direct emissions occur within the project boundary from the site preparation, the use of fossil fuels and fertilizer during biomass production, and the use of fossil fuels during transportation, conversion and distribution of the bioenergy resource. Indirect emissions occur outside the project boundary as a result of the project. Of these, the displacement of pre-project activities may cause significant emissions from deforestation or conversion of grassland to cropland.

We have also discussed the impacts of bioenergy production on agriculture and land-use. In general, increasing bioenergy production will cause a shift in pre-project activities to forest or grasslands due to an increase in prices of agricultural products and the increase incentive to convert new lands to agriculture that results. Evaluating the emissions that the displacement causes is difficult, and as a result, good estimates of the mitigation benefits of bioenergy (i.e. in the CDM) are limited to cases where waste biomass is used or where the lands used for the biomass production have no other competing use. This limits the use of bioenergy as a mitigation option. Methods to improve the assessment of the mitigation benefits of bioenergy will require regional assessments of the displacement that results that incorporate the losses in biomass stocks.

9 ACKNOWLEDGEMENTS

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- [9] Calculation based on soil factors from IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (Table 3.3.4 and table 3.4.5) and an average soil carbon stock of 50 t C/ha prior to land use change.
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