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Viewpoint

Are forestation, bio-char and landfilled biomass adequate offsets for the climate effects of burning fossil fuels?

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ABSTRACT

Forestation and landfilling purpose-grown biomass are not adequate offsets for the CO_2 emission from burning fossil fuels. Their permanence is insufficiently guaranteed and landfilling purpose-grown biomass may even be counterproductive. As to permanence, bio-char may do better than forests or landfilled biomass, but there are major uncertainties about net greenhouse gas emissions linked to the bio-char life cycle, which necessitate suspension of judgement about the adequacy of bio-char addition to soils as an offset for CO_2 emissions from burning fossil fuels.

1. Introduction

When CO_2 emissions from fossil fuels become airborne, their full elimination from the atmosphere takes a very long time. One quarter of fossil fuel-derived CO_2 emissions remains in the atmosphere for several centuries and complete removal of CO_2 may take 30,000–35,000 years (Archer, 2005; Hansen et al., 2008).

Offsetting CO_2 emissions originating in the burning of fossil fuels is the object of growing attention. There is an increasing number of organisations offering 'carbon offsets' (also called 'climate compensation' or 'carbon neutrality') to citizens and organisations, often based on forestation projects (Gössling et al., 2007). The pyrolitic production of bio-char (also called charcoal or black carbon) from biomass to be added to soils has also been suggested to offset fossil-fuel CO_2 emissions (Lehmann et al., 2006; Fowles, 2007; Mathews, 2008). And Saunders (2008) has proposed landfilling of purpose-grown biomass as a 'virtual biofuel', considered to be 'more practical, economic and immediate than biofuels'.

Here, I will consider whether such carbon-offsetting schemes do indeed completely offset the CO_2 emissions linked to burning fossil fuels.

2. Carbon offsetting by forestation projects

A first problem with carbon offsetting by forestation is its duration. The maximum time that forestation projects are guaranteed by the organisations offering carbon offsets by forestation studied by Gössling et al. (2007), is 100 years. This is a much shorter period than the time necessary to remove all fossil-fuel-derived CO_2 from the atmosphere. Even this guaranteed timeframe is questionable in view of (increasing) risks that forests may be destroyed by wild fires and extreme weather events such as storms and droughts (Gough et al., 2008; Nepstad et al., 2008; Van Kooten, 2008) and uncertainty about the permanence of social arrangements safeguarding forests.

A second problem with forestation projects is the occurrence of 'leakage': the de-sequestration of C in response to forestation. Leakage follows from the impact of forestation on land use elsewhere, e.g. because forestation influences land rents and because people dependent on the area where forestry projects are established move elsewhere (Alig et al., 1997; Murray et al., 2004; Sathaye and Andrasko, 2007; Ewers and Rodrigues, 2008). Worldwide an average leakage percentage of about 50% seems to be associated with forestation projects (Sathaye and Andrasko, 2007).

Leakage from, and the limited duration of, carbon sequestration in forestation projects imply that the carbon offsets by forestation are partial and of insufficient duration to completely offset the CO_2 emissions from burning fossil fuels.

3. Carbon offsetting by landfilling purpose-grown biomass

Saunders (2008) has proposed to landfill purpose-grown biomass as an offset to CO emissions from fossil-fuel burning. However, in landfills biomass is largely converted into methane (CH_4). The rate of conversion is dependent on a variety of factors, such as moisture, pH, lignin content and temperature, but is often a matter of decades (Barlaz, 2006; Themelis and Ulloa, 2007).

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Actual emissions of carbonaceous greenhouse gases are dependent on the soil cover which may be conducive to the conversion of methane into CO_2 (Zhang et al., 2008). Capture of CH_4 after conversion in landfills is an option but has in practice limited efficiency (Themelis and Ulloa, 2007; Wanichpongpan and Gheewala, 2007). Moreover methane is, over a period of 100 years, as a greenhouse gas 21 times more potent than CO_2 (Barlaz, 2006). So, landfilling purpose-grown biomass would not seem an adequate offset for CO_2 emissions from burning fossil fuels, but might, in view of the relatively large greenhouse effect of methane, even be counterproductive in mitigating climate change.

There is an additional complication. Purpose-grown crops are also associated with net greenhouse gas emissions. The latter originate during the seed-to-crop stages in the use of fossil fuels, changes in ecosystem (including soil) carbon stocks linked to land use and land use change and may be quite substantial (Reijnders and Huijbregts, 2007; 2008; Searchinger et al., 2008). To the extent that fossil fuels are used, this is at variance with offsetting CO_2 emissions caused by fossil-fuel burning. The reduction of soil and ecosystem C stocks may in turn be offset by the restoration of carbon stocks, but this takes time and thus would not lead to an immediate offset. Also the proposal of Saunders (2008) did not include a guarantee of such restoration.

4. Carbon offsetting by bio-char

In evaluating the effects of producing bio-char and adding that to soils, on greenhouse gas emissions, three matters are important:

- the persistence of bio-char in soils,
- the effects of bio-char on other types of soil carbon and the net emission of greenhouse gases from soils and
- the seed-to-bio-char emission of greenhouse gases.

All three matters have so far only been studied in a limited way.

There is evidence that bio-char may persist in soils over thousands of years (Carcaillet and Talon, 2001; Long et al., 2007; Kaal et al., 2008). There are also reports about the decomposition of bio-char in the field and the biotic and abiotic degradation of bio-char in laboratory settings, with rates partly depending on the production procedure (Cheng et al., 2006; Hockaday et al., 2006; Lehmann et al., 2006; Wengel et al., 2006; Steiner et al., 2007; Bruun et al., 2008). Carbohydrates which can be easily metabolized may be conducive to the decomposition of bio-char (Hamer et al., 2004). It has been suggested that decomposition of bio-char in the field may be on a centennial scale (Hockaday et al., 2006). Regarding permanence, this would qualify properly produced bio-char as a potential offset for fossil-fuel-derived CO_2 emissions.

As to the effects on other types of soil carbon, there is evidence for a positive effect of bio-char on crop productivity which in turn could have a positive effect on soil carbon sequestration (Glaser et al., 2001; Steiner et al., 2007; Lehmann et al., 2007). On the other hand there is also evidence that, due to stimulation of soil biological processes, bio-char may actually lead to a loss of native soil carbon in boreal forests (Wardle et al., 2008a, b).

As yet, much of the dynamics regarding the impact of bio-char on other types of soil carbon remains unknown and it may well be that the actual effect on soil organic matter may vary depending on the nature of bio-char and the soil to which bio-char is added (Wardle et al., 2008a).

There has been limited research into the effects of bio-char on soil emissions of the greenhouse gases N_2O and CH_4, which suggests that such emissions may be lowered by bio-char addition (Gaunt and Lehmann, 2008). No research has been found regarding the effect of bio-char on the uptake of CH_4 and N_2O by soils. N_2O is a significant greenhouse gas in this context because its estimated mean atmospheric residence time is 118 ± 25 years (Stein and Yung, 2003) and its greenhouse effect is 296 times that of CO_2 within a time horizon of 100 years (Reijnders and Huijbregts, 2008).

Seed-to-bio-char greenhouse gas emissions have been studied for purpose-grown Miscantus, corn and switchgrass and for the use of the crop residues wheat straw and corn stover by Gaunt and Lehmann (2008). This study considered the CO_2 and N_2O emissions linked to seed-to-bio-char fossil-fuel consumption. Crops grown for the purpose of bio-char production compete for good soils with other crops, which – due to the relative inelasticity of the demand for food – has an impact on land use change which in practice tends to cause lower ecosystem C stocks (Searchinger et al., 2008). And diverting crop residues to bio-char production reduces (ceteris paribus) the addition of such residues to soils, which in turn has a negative impact on soil C stocks (Reijnders, 2008). Both reductions of C stocks lead to net emissions of carbonaceous greenhouse gases to the atmosphere, an impact that was neglected in the study of Gaunt and Lehmann (2008). This impact is at variance with the intended offset. In theory the C stocks may be restored. But as yet proposals for bio-char use do not include this provision.

There is major uncertainty about the N_2O emissions linked to the bio-char life cycle (Reijnders and Huijbregts, 2008) and it has been suggested that N_2O emissions linked to the cultivation of crops may have been underestimated by studies such as those of Gaunt and Lehmann (2008), (Crutzen et al., 2007).

Thus, largely due to limited experimental data, it as yet cannot be determined whether applying bio-char to soils is an adequate offset to CO_2 emissions from burning fossil fuels.

5. Conclusion

Forestation and landfilling purpose-grown biomass are not adequate offsets for the CO_2 emission from burning fossil fuels. Their permanence is insufficiently guaranteed and landfilling purpose-grown biomass may even be counterproductive in view of the relatively large greenhouse effect of methane and the substantial greenhouse gas emissions that may be associated with biomass cultivation. As to permanence, bio-char may do better than forests or landfilled biomass, but there are major uncertainties about net greenhouse gas emissions linked to the bio-char life cycle, which necessitate suspension of judgement about the adequacy of bio-char addition to soils as an offset for CO_2 emissions from burning fuels.

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