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THE GLOBAL ECONOMIC LONG-TERM POTENTIALOF MODERN BIOMASS IN A CLIMATE CONSTRAINED WORLD

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Overview

Low-stabilization scenarios consistent with the 2 °C target project large-scale deployment of purpose-grown lignocellulosic biomass. While the scientific consensus on the importance of bioenergy for climate change mitigation is strong (Rose *et al* 2013), high uncertainties remain regarding the biomass potential mainly due to uncertainties about future developments of agricultural yields, demand for food and feed, and availability of land and water for agricultural production. In particular, there are only few global studies attributing costs or prices to the estimated bioenergy potential. In case a greenhouse gas (GHG) price regime integrates emissions from energy conversion *and* from land-use/land-use change, the strong demand for bioenergy and the pricing of terrestrial emissions are likely to coincide. We explore the global potential of purpose-grown lignocellulosic biomass and ask the question how the supply prices of biomass depend on prices for greenhouse gas emissions from the land-use sector.

Method

Using the spatially explicit global land-use optimization model MAgPIE (Lotze-Campen *et al* 2008) that treats technological change endogenously we construct bioenergy supply curves under full land-use competition for 10 world regions and a global aggregate in two scenarios, with and without a GHG tax. The tax incentivizes the reduction of emissions accruing from land-use change (CO_2) and agricultural production (N_2O, CH_4). Regarding CO_2 the tax is applied exclusively on the forest land pool, i.e. emissions from land-use change of other available land types are not taxed. The bioenergy supply price curves are derived by measuring the price response of the MAgPIE model to different global bioenergy demand scenarios. The time horizon reaches from 2005 to 2095 in five year time steps. Each bioenergy demand scenario yields a time path of regional allocation of bioenergy production and global bioenergy prices. For each region and time step the supply curve was fitted to the resulting combinations of bioenergy production and bioenergy prices.

Results

We find that the implementation of GHG taxes is crucial for the slope of the supply function and the GHG emissions from the land-use sector. Global supply prices start at 5 $/GJ and increase almost linearly, doubling at 150 EJ (in 2055 and 2095). The GHG tax increases bioenergy prices by 5$/GJ in 2055 and by 10 $/GJ in 2095 since it effectively stops deforestation and thus reduces the amount of land available for bioenergy production. Prices additionally increase due to costs for N_2O emissions from fertilizer used for bioenergy production. The GHG tax decreases total global land-use change emissions by one third. However, we observe a carbon leakage effect occurring from conversion of land that is not under emission control.
If forest is not protected by the GHG tax, bioenergy emissions account for 63 $GtCO_2$, mainly due to deforestation in Latin America (40 $GtCO_2$). Under the GHG tax there is no deforestation for bioenergy, but substantial expansion into other land that is not under emission control, predominantly in Pacific Asia (73 $GtCO_2$). This leakage effect increases bioenergy emissions by 54 % to 97 $GtCO_2$ cumulated from 2005 to 2095.
Bioenergy production requires substantial amounts of land, almost 500 million ha (Mha) for 240 EJ in 2095. With and without the GHG tax this is predominantly realized by crop land reduction (intensification) and usage of other land (e.g. non-forest natural vegetation, present and future abandoned land). Average yields required to produce 245 EJ in 2095 are roughly 600 GJ/ha with and without tax.

Conclusions

Climate policy not only increases the demand for bioenergy as several studies show (Rose *et al* 2013, Calvin *et al* 2009, van Vuuren *et al* 2010), it could also substantially increase supply prices of biomass raw material as the present study shows. Imposing the GHG tax prevents deforestation, lowers carbon emissions, reduces land available for bioenergy production and increases the opportunity costs of land. The bioenergy prices presented in this study emerge under full land-use competition with other crops and are therefore higher than pure production costs on abandoned land presented in other studies (Hoogwijk *et al* (2009), Vuuren *et al* (2009)). Also, compared to other energy carriers (4.6 $2005/GJ for coal in 2011, (IEA 2012)) bioenergy prices presented here may seem high. However, bioenergy supply at these prices could get relevant, since under climate policy the energy system shows high willingness to pay for bioenergy (Klein *et al* 2013). The incentive to pay high prices for bioenergy and to create negative emissions from it increases with the carbon price. Results show that high bioenergy demand and high GHG prices, which are likely to coincide under climate policy that embraces all sectors, can put substantial pressure on the land-use system. Bioenergy production requires large amounts of land, predominantly realized by crop land reduction (intensification) and increased usage of other land.
This study illustrates the potential consequences of a sectoral fragmented climate policy in the land-use sector: While effectively preventing deforestation the tax could induce a carbon leakage effect resulting from conversion of land that is not included into

the tax or a forest conservation scheme. This exemplifies the relevance of land pooling policies for the supply of biomass. Therefore, the results emphasize that, albeit a complex task, an effective climate policy in the land-use sector has to be implemented carefully to guarantee a comprehensive accounting of different emission sources and that this climate policy may require accompanying protection measures that prevent bioenergy or agriculture from expanding into land that is not under emission accounting and that exhibits high carbon stocks or other features valuable to protect. This is particularly important if bioenergy is used as a mitigation option.

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