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CHAPTER XI

Greenhouse gas mitigation in land use – measuring economic potential

INTRODUCTION

As noted in other sections the global *technical* mitigation potential of agriculture, excluding fossil fuel, offsets from biomass is around 5.5–6 Gt CO_2eq/year. This can be delivered through a range of technically effective measures that can be deployed in a variety of farm and land-use systems. These measures can be deployed at varying cost, including a range of ancillary environmental and social costs and benefits that need to be taken into account when moving to some consideration of the socio-economic potential of mitigation pathways. This chapter will explore the distinction between the technical and economic potential as applied more generally to land-use mitigation measures. Specifically, the chapter considers how issues of efficiency and equity are important corollaries to the effectiveness of grassland mitigation. The consideration of efficiency is made with reference to a carbon (C) price, which provides a benchmark cost for comparing mitigation options on a cost per tonne basis. The equity dimension then addresses the distributional impacts arising if efficient measures are adopted across different income groups. We demonstrate these points with the example of biochar, a soils additive that is widely considered to offer a low-cost mitigation potential applicable in a wide variety of high- and low-income farm and land use systems. This example is used to illustrate the data requirements for developing a bottom-up marginal abatement cost curve, which is essential for judging the relative effectiveness and efficient of mitigation measures.

DEFINING ECONOMIC POTENTIAL

Grassland and soil sequestration offer a suite of mitigation measures that can potentially be implemented across a wide area of the world, offering significant abatement potential for specific countries. But much of this potential may be an expensive way to mitigate emissions. In other words, the large technical potential noted by the United Nations Framework Convention on Climate Change (UNFCCC, 2008) does not tell us whether this form of sequestration is worth doing, relative to a suite of other methods for avoiding greenhouse gas (GHG) release. An important subsidiary question therefore is to determine the country- or region-specific extent of economically efficient mitigation, which will be something less than technical potential.

Determining the economic potential requires the calculation of the cost per tonne of abating carbon dioxide equivalent (CO_2eq) by alternative mitigation measures. In essence, in attempting to meet an emissions obligation,[1] any country needs to compare the relative costs of alternative ways to mitigate. These costs will vary within agriculture and land use, and between this sector and others (e.g. energy or transportation). A country will develop an efficient mitigation budget by choosing the lowest cost options available. In most sectors, mitigation options can be ranked from the cheapest (USD/tonne/CO_2eq) to the most expensive. At some point, the cost of implementing the next (or marginal) abatement measure is such that it is more efficient to switch to other mitigations in other sectors that offer lower cost mitigations. At the limit, a measure can be judged as efficient relative to the C price.

A C price (see Box) provides a cost benchmark or threshold for considering "efficient" mitigations. We can say that any options that can potentially mitigate tonnes of CO_2eq at or less than the price per tonne should fall into our efficient emissions budget or our estimation of the economic potential (previously mentioned by UNFCCC). Those that cost more than this should be excluded.

MARGINAL ABATEMENT COST CURVES

The process described above is the essence of developing a marginal abatement cost curve (MACC) for emissions mitigation. MACC analysis is proving useful to show how countries and subsectors can derive an economic abatement potential and develop efficient emissions budgets (see, for example, McKinsey & Company, 2009). MACCs for agriculture and land use are more complex to derive, but offer a useful framework for benchmarking the potential efficiency of grassland mitigation.

[1] Note that developing and developed countries differ in the extent to which this is a legally binding obligation.

The relevance of a carbon price

There are two C prices (expressed as CO_2eq) that can be used to determine the value of avoided emissions. These are the shadow price of carbon (SPC) or, alternatively, the cost of purchasing emissions allowances in any trading regime such as the European Trading Scheme (ETS).

The ETS is a trading scheme set up by the European Union as part of an (emissions) cap and trade scheme. This means that the EU has effectively set a limit on the amount of C emissions allowable from certain EU industries (e.g. energy providers) that must purchase permits if they want to emit more tonnes. This permit price provides a basis for valuing C. Notionally, the value of a permit can be equated with the value that a polluter might have to pay a farmer or land manager to avoid the release of or offset a tonne of C. Alternatively the permit is the price that a farmer might consider in deciding whether to mitigate an emission themselves or pay for the right to emit. If the permit is cheaper than the cost of preventing the emission then the permit purchase makes sense.

Globally, agriculture does not yet have to hold emissions permits, so the ETS price is only a notional market value that *could* be used to value emissions.

The SPC is currently the received approach to value policy impacts related to climate change. It is the notional value assigned to the damage caused by the release of a marginal (one extra) tonne of CO_2. This value is calculated by damage cost modelling and converting the damages to a present value equivalent. The SPC is used by several national governments to appraise projects or policies with a GHG release or mitigation element. In this context, it provides a suitable unit value of the damage avoided because of the C stored in soils or elsewhere in farm systems.

The SPC tends to be higher than the ETS since the latter is determined by specific demand and supply conditions relating to the initial allocation of emissions permits, prevailing economic conditions in the demanding industries and the shape of international agreements post-Kyoto. The value of a given policy that leads to GHG emissions mitigation by farmers is simply the quantity of gas mitigation (in tonnes) multiplied by the SPC price (DEFRA, 2007).

MACC variants are broadly characterized as either top-down or bottom-up. The top-down variant describes a family of approaches that typically take an externally determined emission mitigation requirement that is allocated downwards through different types of economy-wide models that characterize industrial structures and sector emissions mitigation costs associated with a suite of largely predetermined abatement measures. Such models determine how much of the emissions obligation can be met by a specific sector depending on relative cost differentials (Ellerman and Decaux, 1998). The-top down variant will be limited by the specific characterization of mitigation possibilities within the different sectors. For agriculture and land use, the approach necessarily assumes a degree of homogeneity in abatement potential and implementation cost over the regions described by MACC (see, for example, De Cara, Houze and Jayet, 2005). For many industries, this assumption is appropriate. For example, power generation is characterized by fewer firms and a common set of relatively well-understood abatement technologies. But agriculture and land use are more atomistic, heterogeneous and regionally diverse, and the diffuse nature of agriculture could alter abatement potentials and cost-effectiveness. This suggests that different forms of mitigation measure can be used in different farm and grassland systems and that there may be significant cost variations and ancillary impacts.

Bottom-up MACC approaches address some of this heterogeneity. The bottom-up approach can be more technologically rich in terms of mitigation measures and accommodating variability in cost and abatement potential within different land-use systems. In contrast to the top-down approach, an efficient bottom-up mitigation budget is derived from a scenario that first identifies the variety of effective field-scale measures, then determines the spatial extent to which these measures can be applied across diverse farm systems that can characterize a country or region. More specifically, it is the application over and above a business-as-usual baseline mitigation activity level that determines an abatement potential. The efficiency of this potential is set by the amount below the C price threshold.

Recent work to determine a bottom-up MACC for United Kingdom agriculture and land use (Moran *et al.*, 2010) demonstrates the complexities of developing emissions budgets for agriculture, forestry and land use. Specifically, the measurement of abatement potential for many measures is biologically complex because of interactions and the determination of additionality of a baseline is also challenging. However, MACC exercises are useful for organizing relevant cost (private and social) and effectiveness information that is currently either unavailable or anecdotal rather than gathered in any systematic way. Both the bottom-up and top-down methods suggest that agriculture and land use can offer win-win and low-cost mitigation options (see Figures 25 and 26). In the figures, each bar represents a mitigation measure. The width of the bar represents the volume of gas abated by the application of the measure over all possible sites, while the height of the bar represents the cost per tonne.

The win–win cost picture (Figure 25) is attributed to the fact that some measures can actually be cost negative. For example, the correct application of nitrogen (N) fertilizer can yield a financial saving to a farmer and also reduce diffused pollution to water. The latter is an ancillary benefit to society.

Existing cost-effectiveness evidence presented in the International Panel on Climate Change (IPCC, 2007a) is based on top-down MACC analysis (Figure 26), derived largely from information presented in the United States Environment Protection Agency (US-EPA, 2006). As such, the information is presented as regional estimates with only qualitative estimates of ancillary benefits likely to arise from measure implementation. As agriculture is more fully integrated into emissions abatement targets, more emphasis is likely to be placed on the development of national bottom-up MACC estimates with attention paid to measures that integrate mitigation and adaptation objectives and that can simultaneously address poverty objectives. The latter objective is likely to be particularly relevant to land use measures in developing countries.

BIOCHAR AND LAND USE MITIGATION

Land use may act as either a source or a sink of C, depending on the effect on soil and plant processes that are disturbed. For example, increased emissions caused by fertilizer use may be partially offset by increased rates of photosynthesis in plants that are no longer limited by a lack of nutrients. Models of the global C balance predict that current C sinks created by disturbance to land by human activities may disappear by 2050, converting land to a net source of C emissions (IPCC, 2000). Biochar technologies offer a mitigation solution that may correct this imbalance and is therefore of particular interest to scientists and policy-makers.

Biochar is the charred product of biomass heated without oxygen (a process known as pyrolysis), in which a high proportion of C remains within its structure. Carbon is stabilized during pyrolysis, which converts it to a form that is highly recalcitrant and not easily mineralized (Forbes, Raison and Skjemstad, 2006; Chan and Zhihong, 2009). Pyrolysis is a technology that can be realized on many different scales, from specially designed wood burning stoves to industrial plants, which process thousands of tonnes of biomass feedstock every year (Brown, 2009). After production, biochar would be applied to agricultural soils in order to yield the many benefits that have been advocated to it and that may offset the costs of production. In agricultural soils, biochar has been experimentally shown to double grain yields, improve soil fertility and increase water retention (Sohi *et al.*, 2009). This may improve the cost-effectiveness of biochar compared with other mitigation technologies. The versatility of biochar technologies also offers potential as a poverty-focused technology transfer and use in developing countries.

New technologies often have a higher associated risk than more established technologies, because of uncertainties in their development and deployment, which may affect their eventual cost and effectiveness. Despite initial enthusiasm, uncertainties exist about biochar's emissions abatement potential, as well as the cost of its deployment on a commercial scale (Lehmann and Joseph, 2009). The costs and social impacts of biochar projects are only beginning to be explored.

This section attempts to locate biochar on a global MACC of abatement technologies. We identify abatement potential as a global land use and associated cost. The exercise draws on more detailed analysis presented in Pratt and Moran (2010).

BIOCHAR TECHNOLOGIES

Biochar can be produced using different technologies that are suitable for small- and larger-scale production. For example, modifications to stoves and kilns used in rural areas of the developing world offer a low-technology, low-cost method of producing biochar by pyrolysis. Biochar stoves have the added advantage of being more efficient and less smoky, greatly improving the lives of their users. Larger pyrolysis plants are expensive to build and run but offer greater returns in abatement potential and efficiency (Brown, 2009). Such technologies are favoured in developed nations where there is an abundance of residue biomass for feedstock and adequate infrastructure, and better access to start-up capital.

Differences in production costs and bio-product value are important considerations in determining economic feasibility. Fast pyrolysis is performed at higher temperatures and yields more bio-oil and syngas products compared with slow pyrolysis, which produces greater quantities of biochar. There is already an established demand for bio-oil (and, to a lesser extent, syngas), which can be used to generate electricity and fuel for transport (McCarl *et al.*, 2009). If the economic benefits of these are greater than those of making biochar for agricultural (yield) benefits, then there will be pressure to use fast pyrolysis, the technique that produces more bio-oil and less biochar as a consequence.

Technical and economic potential

The determination of the technical potential of biochar depends on the scale of production, the ancillary yield effects of application to soil and the permanence assumptions made. Experimental evidence shows considerable variation depending on soil types and associated practices (Pratt and Moran, 2010). These elements also affect the economic potential, especially the question of whether the costs of implementing biochar mitigation can be offset by the ancillary agricultural benefits.

Two biochar scenarios for 2030 are considered in detail: large-scale biochar processing plants using both slow and fast pyrolysis in developed countries; and biochar stove and kiln projects in developing regions. The year 2030 was taken as an appropriate middle point between today and 2050 – the date by which most scientists agree we must have significantly reduced our emissions in order to prevent 2 °C or more rise in global temperature (IPCC, 2007b). Developed regions were split into three geographic areas: North America, Europe and the developed Pacific. Countries within these regions were considered if they had a population of one million or more and a GDP per capita exceeding USD20 000. Biochar projects for these regions were based on a hypothetical study of a pyrolysis plant, which processed 70 000 tonnes of feedstock per year. This cost model draws on the example in McCarl *et al.* (2009), based on empirical data from a pyrolysis plant in the United States of America.

Developing regions were also split into geographic areas: Africa, Asia and Latin America. Countries with populations of one million or more and a GDP per capita below USD20 000 were included. Biochar projects in these regions were based on a study of stoves and charcoal kilns modified to produce biochar. Calculations are based on a hypothetical study by Joseph (2009), which draws on real data from improved stove and charcoal kiln projects in a tropical Asian country (Edwards *et al.*, 2003; Limmeechokchai and Chawana, 2003; Joseph, Prasad and Van der Zaan, 1990).

To assess the abatement potential of biochar projects, estimates of both the abatement potential per project type, and the likely timing and number of biochar projects set up in each region up to 2030 were made (Pratt and Moran, 2010).

The amount of biochar produced in both the pyrolysis plant and stoves projects was taken directly from the research papers, but was then modified to fit the circumstances of each region. The C storage potential of biochar, which considered the C content of biochar made from different feedstocks, the different ratios of biochar to bio-oil and syngas products from fast and slow pyrolysis techniques, and the initial C loss observed in biochar applied to soils was calculated to give an abatement potential per project. Other factors likely to limit biochar and C storage ability, such as restrictions on areas where biochar can be applied because of risks of fire and erosion were identified, but could not be considered because of lack of data.

For the future, abatement potential and scenarios for the number and timing of projects in each region by 2030 were developed. In developed regions, the number of biochar processing plants was based on the number of biofuel plants in operation in these regions today (Bakker, 2009). The number of biofuel plants was used as a guide to future biochar plant development because it represents the willingness and capabilities of each developed region to take up new technologies in the biotechnology field and, therefore, may relate to future regional enthusiasm for biochar projects

A maximum abatement potential and cost-effectiveness were quantified, using the following process modified from Moran *et al.* (2008):

- quantify the costs and benefits and the timing of costs and benefits;
- calculate the net present value of project costs and returns;
- express costs in terms of USD, 2008.

For MACC, the abatement for all the mitigation solutions were summed to give a total abatement potential up to 2030 (Gt C/year). Each solution was added to the MACC in order of their cost-effectiveness. MACC curves were created using the software program ThinkCell® (Think-Cell Software GmbH, 2009).

Fast pyrolysis in Europe and slow pyrolysis in the developed Pacific are cost-effective under the current assumptions. Fast pyrolysis in Europe was the most cost-effective of all the large-scale biochar projects considered in the developed regions. The sensitivity analysis indicated that the bioproducts of pyrolysis (if bio-oil and syngas are used to substitute fossil fuel electricity generation) become more valuable for assumed higher electricity and C prices in Europe. Pyrolysis projects in North America, while being the least cost-effective, have the largest abatement potential. This is because the high current investment in biomass technologies and the large amounts of agricultural waste that could be used as biochar feedstock mean that it would be possible to have many biochar pyrolysis plants.

MACC in Figure 27 shows that biochar projects in the developing regions are more cost-effective and abate more CO_2 than biochar projects in the developed regions, despite the advantages of more efficient, high technology and better infrastructure in developed regions. This difference in abatement potential comes down to the larger number of low-cost projects that can be set up.

The global MACC in Figure 28 indicates that high C price biochar projects in Asia and Latin America are competitive relative to other climate change mitigation measures being explored today. Even the most expensive biochar projects rival the cost-effectiveness (but not the abatement potential) of the most expensive technologies considered, such as C capture and storage (CCS). According to this MACC, biochar projects in developing countries appear to offer more abatement potential at lower costs than CCS.

UNCERTAINTIES

As with other mitigation technologies, biochar needs to be evaluated in terms of three basic criteria: effectiveness (what works?), efficiency (is this a relatively inexpensive mitigation technology?) and equity (are adoption scenarios fair?). This example focuses predominantly on efficiency and suggests that some biochar options are indeed cost-effective. But the conclusion can be tempered by several factors that affect biochar effectiveness. The issue of equity also warrants further attention.

On effectiveness, several factors that could have altered the cost and abatement potential of biochar projects could not be included in this analysis because of a lack of data. If reductions in nitrous oxide (N_2O) and methane (CH_4) emissions from biochar soil application are shown to be substantial and consistent, the possible abatement potential of biochar could increase dramatically (Sohi *et al.*, 2009). However, these estimates of avoided emissions may be exaggerated because of the recorded limitations of biochar without N fertilizers in field experiments. Many of the experiments conducted today show that high yields only occur if biochar application is accompanied by N fertilizer, in the form of manure or chemicals. This may mean that many of the reductions in N_2O emissions cannot be realized if yield gains are the primary objective of biochar projects.

Although our estimates of biochar abatement potential may increase over time (if suppressions of N_2O and CH_4 emissions are included, for example), other variables not currently considered could work against this and reduce the C storage potential of biochar. One is the exclusion of biochar application to soils that are prone to fires. Although research in this area is limited, anecdotal evidence from forest fires in Siberian boreal forests suggests that naturally occurring biochar can be removed rapidly from soils (Woolf, 2008). The possibility of increased risk of wild fires resulting from climate change and slash-and-burn land clearance may continually pose a risk to C storage by biochar in areas where this practice is prevalent.

EQUITY IMPLICATIONS

A number of social barriers also need to be considered as part of any potential deployment of biochar technology. In developing regions, the biochar stove projects must reach the poorest and most isolated members of the population – a challenge in itself (S. Lagrange, personal communication, 24 June 2009). Low-income households are often extremely risk averse and loyal to their traditional methods of farming – a change in traditional methods that has been tried and tested over many generations could result in a reduction of much-needed food supplies for the following year. However, changes in climate are already happening and predicted to affect the poorest regions of the world the most (IPCC, 2007b). Therefore, traditional practices may have to be adapted as climate change reduces the effectiveness of once reliable methods. Adaptations will have to be made and improvements in soil conditions and agricultural production resulting from new techniques involving biochar production may be necessary (P. Read, personal communication, 4 June 2009).

In developed regions, people are richer and less risk averse but other social barriers exist with delivering new technologies. Negative views of abatement technologies and a mistrust of government policies could have severe consequences for biochar application. Biochar has been linked with biofuels, a particularly mistrusted technology. Activism groups, such as Biofuel Watch, have been quick to voice concerns relating biochar to the problems associated with biofuels (Ernsting and Smolker, 2009).

The risks voiced by Biofuel Watch and others must be taken seriously. A potential problem with large-scale biochar deployment is the dual aims of such projects: agricultural benefits and environmental benefits. Where there are multiple aims, often one will come to dominate, at the cost of others. If the profits of biochar projects are seen to come mainly from the agricultural benefits, then large, powerful agronomic companies may invest in the technology. Like bioethanol production in the United States, biochar could be produced for agricultural benefits regardless of the environmental effects – if this happens there is a real danger that the C storage potential of biochar will be overlooked, leading to all too familiar consequences for GHG emissions.

One possible solution would be to consider only waste biomass – crop and timber residue and sewage from cities and farm animals – as the biomass feedstock (Lehmann, Gaunt and Rondon, 2006). Not only would this remove the problem of competing for suitable land with food crops, but it could alleviate some of the problems caused by waste. The feedstock needs of biochar production in developed countries, as considered in this analysis, could easily be obtained from current volumes of waste biomass. If waste biomass were used for biochar production, producers could add tipping fees to their profits if they were willing to take materials that would otherwise have to be treated or dumped in landfills (McCarl *et al*., 2009). However, supporters of this solution have yet to explain how biochar producers could be persuaded to use only waste materials, which are rejected for biofuel production today. It is clear that, as well as scientific research, other precautions, such as economic drivers, incentives and even legalization, will need to be in place before biochar can become the planet-saving solution that some experts advocate (Sohi *et al*., 2009; Lehmann and Joseph, 2009).

CONCLUSIONS

This chapter serves as a reminder that global land uses need to be considered within the overall suite of methods for mitigating GHGs. As in other sectors, land use offers a range of measures that are technically effective in many farming systems. But effectiveness does not always guarantee that the same measures offer abatement potential that is economically efficient or that considers wider social impacts.

As agriculture and land-use change are pulled into national and international negotiations on GHG mitigation, the sector will require a more discriminating analysis of low-cost and win-win potential. The MACC analysis outlined here provides a useful adjunct to the continuing scientific definition of mitigation effectiveness. It also provides a prerequisite to the development of a rational approach to delivery of an efficient mitigation budget from the sector. This budget can be delivered through a range of policy instruments, voluntary measures, command and control (CoC), and market-based instruments (MBI).

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