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Using forests for climate mitigation: sequester carbon or produce woody biomass?

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Abstract Forests can mitigate greenhouse gases by storing carbon (SEQU) and supplying woody biomass for burning in power plants with CCS (WBCCS). The paper uses GTM to understand the global dynamics of forests and WITCH to determine the most cost-effective mitigation methods to limit long-term radiative forcing. The analysis finds that both SEQU and WBCCS are effective but the most effective choice is to use them together. WBCCS + SEQU accounts for 23–28% of all mitigation. SEQU initially dominates while carbon prices are low while WBCCS becomes more important later with especially high carbon prices. Forest mitigation encourages land use to shift towards forests, increasing natural forests and especially managed forests. SEQU leads to larger trees and more natural forestland and WBCCS leads to faster growing trees and more managed stands.

1 Introduction

Most integrated assessment models (IAMs) conclude that strict temperature targets require both storing carbon in forests (carbon sequestration-SEQU) and using bioenergy with carbon capture and storage (BECCS) as an alternative energy source (Clarke et al. 2014; Rogelj et al. 2015). Many of these models assume that BECCS should be provided primarily by either crop biomass or agricultural and forestry residues (Creutzig et al. 2015). Crops grown on prime farmland have a higher NPP than forests. However, a massive shift of prime farmland away from crops will dramatically increase the price of crops. Market forces will react to this global

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increased demand for cropland by significantly expanding into forestland (Searchinger et al. 2009; Delucchi 2010; Hertel et al. 2010). If crop-supplied biomass causes a large loss of carbon in forests, it would no longer be the most effective fuel for BECCS. Crop biomass could be secured from low productivity grasslands instead of prime farmland. But such grassland has a relatively low NPP compared to forests, and the costs of collecting dispersed material across vast grasslands are relatively high (Chum et al. 2011). A recent analysis found that woody biomass for power plants with carbon capture and storage is an effective, though expensive, mitigation strategy (Favero and Mendelsohn 2014). But would woody biomass for burning in power plants with CCS (WBCCS) be compatible with a SEQU program to store even more carbon in forests? This paper analyzes how WBCCS + SEQU would work together and compares the results with using just SEQU or just WBCCS.

There is an extensive literature on using SEQU alone which suggests that forest carbon sequestration is an effective tool to store carbon (Moulton and Richards 1990; Plantinga et al. 1999; Stavins 1999; Richards and Stokes 2004; Houghton et al. 2015). Natural forestland can be expanded, and managed forest rotations can be lengthened to store substantial amounts of carbon at relatively low cost. Forests can potentially sequester 7–11 $GtCO_2$/year for carbon prices up to 100 USD/tCO_2 (Smith et al. 2014; Sohngen and Mendelsohn 2003). Provided mechanisms can be created to encourage efficient forest carbon sequestration, SEQU is a low cost carbon mitigation technology.

There are, however, only a few studies that investigate the implications of using WBCCS and SEQU together as a climate mitigation policy (Wise et al. 2009, 2015; Edmonds et al. 2013; Calvin et al. 2014; Humpenöder et al. 2014; Smith et al. 2016). All of these studies have a complete land use model and so are capable of determining how land use changes over time. But none of these models have a dynamic forestry sector, so it is not clear how the forest sector would respond to these policies. For example, the previous literature could not see that SEQU programs cause trees to become older and larger. In contrast, WBCCS encourages forests to increase growth, and so, it leads to more managed forests. Given a global forest, how would these two programs interact over time? Where should SEQU be used versus WBCCS? Do the two programs enhance each other or compete for the same resource? Which tool would dominate in a program that allows both? Do the answers to the above questions depend on the severity of the long run radiation forcing targets (the price path of carbon)?

This paper seeks to answer these questions using the global model of forests, GTM (Sohngen et al. 1999; Sohngen and Mendelsohn 2003) and the IAM WITCH (Bosetti et al. 2006). This is the first analysis of WBCCS+ SEQU by the combination of these two state-of-the-art global, intertemporal optimization models. WITCH evaluates the most cost-effective combination of mitigation methods given a long run radiative forcing target. GTM provides estimates of how forests would dynamically respond to these mitigation policies. Putting the two models together allows the analysis to determine what role forest mitigation should play in an overall greenhouse gas mitigation plan. We examine three alternative long-term radiative forcing targets in order to understand what role the severity of mitigation plays in these decisions. This is important because the forest mitigation strategies are the only currently effective technologies that can directly reduce carbon concentrations (remove carbon dioxide from the atmosphere). All other mitigation strategies simply prevent more carbon from being emitted. Forest mitigation is therefore more important; the more stringent the mitigation plan, the lower the radiative forcing target and the lower the final desired global temperature.

This paper makes several important contributions. The paper calculates the optimal dynamic mix of WBCCS + SEQU given three Representative Concentration Pathways (RCPs):

2.6, 3.6, and 4.5 W/m^2. These concentrations correspond to expected temperature increases of 2.0, 2.3, and 2.9 °C, respectively, in 2100. The analysis predicts the overall mitigation done by forests, how each region contributes to forest mitigation, what happens to the mix of natural versus managed forestland, how management intensity changes, and how the program affects the global market for timber.

The paper is organized as follows. Section 2 describes the model and methods used in the analysis. Section 3 discusses the forest-based carbon mitigation results under different climate policy scenarios. Finally, Sect. 4 summarizes the results and discusses the policy implications.

2 Methods

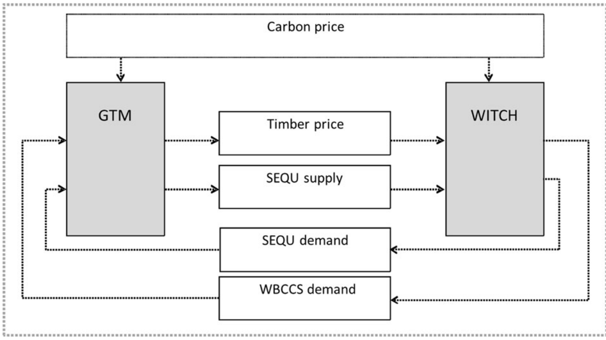
The IAM WITCH examines a host of mitigation alternatives and a radiative forcing target to generate a carbon price path over time and an efficient package of mitigation technologies (Bosetti et al. 2006, 2007, 2009). WITCH provides a demand for mitigation technologies given a climate mitigation target (which we vary across simulations). WITCH also provides a set of supply function for energy-related mitigation. GTM is a global model that combines the spatially and temporally detailed predictions of BIOME3 (Haxeltine and Prentice 1996) with an economic model that weighs optimal forest management alternatives (Sohngen et al. 1999; Sohngen and Mendelsohn 2003). GTM provides a supply function for both WBCCS and SEQU in the context of a global timber market.

This study uses a soft link between WITCH and GTM to equate supply and demand for forest-related mitigations over time to determine the most efficient use of all mitigation technologies including WBCCS and SEQU. The soft link is not new and has been used before to link GTM with IAMs to calculate optimal sequestration programs (Sohngen and Mendelsohn 2003; Tavoni et al. 2007) and to estimate the optimal use of woody BECCS (Favero and Mendelsohn 2014, 2017). However, a dynamic forest model of WBCCS + SEQU together has not been done before.

Figure 1 describes the soft link of the two models. Given a stabilization target, WITCH examines all possible mitigation policies to determine the most cost-effective strategy for reaching that target. This generates a carbon price path for each stabilization target. WITCH calculates the size of the forest mitigation demand given the price of timber over time. The price of timber is initially determined by the BAU (no mitigation) scenario. The resulting carbon price path for sequestration and the quantity of woody biomass needed over time for WBCCS are then entered into GTM. GTM calculates the planting, harvesting, and management intensity in the forest to meet these additional requirements. The resulting price of timber over time is then entered back into WITCH so that it can calculate the cost of both SEQU and WBCCS. This process is reiterated until the adjustments between iterations become very small. This soft-linking of an integrated assessment model and GTM has been successfully implemented in several previous studies (Sohngen and Mendelsohn 2003; Tavoni et al. 2007; Favero and Mendelsohn 2014, 2017). In practice, it takes several iterations to equilibrate the supply in GTM over time with the demand from WITCH. The resulting equilibrium reveals a dynamic path of timberland, management intensity, and harvests in GTM, a path of carbon and timber prices and forest carbon sequestration in both models, and a path of carbon mitigation and technologies in WITCH. It is this final dynamic outcome that is reported in this paper.

Under every climate mitigation scenario, the mitigation program begins in 2020 and the results are examined through 2100. All decision makers face a single carbon price worldwide.

Fig. 1 Soft link between WITCH and GTM



In the energy sector, every fuel used faces a common charge that reflects its net emission of CO_2 to the atmosphere. For each climate mitigation scenario, WITCH assures that the outcome takes into account the competition between WBCCS and other mitigation options. In particular, WBCCS is assumed to be produced with woody biomass in integrated gasification combined cycle (IGCC) power plants with CCS. WBCCS power plants are assumed to buy woody biomass from the international market at the market clearing price, given by GTM. WBCCS thus provides three services. First, it supplies electricity. Second, it captures CO_2 using CCS. Although expensive, we assume that storing carbon underground from CCS is possible. Third, WBCCS temporarily stores carbon in forests in anticipation of the trees being burned in power plants (Sedjo and Tian 2012). In previous research, WBCCS was given a subsidy equal to the average value of this sequestration (Favero and Mendelsohn 2014, 2017). In this study, the carbon sequestration value of WBCCS is directly valued by SEQU. The carbon price from the SEQU program will be more efficient than the indirect subsidy because it reflects the marginal value rather than the average value of the sequestration.

For each carbon price scenario, GTM takes into account the competition between industrial wood products, woody biomass and forest carbon sequestration, the intensity of forest management, the competition for land between forestry and agriculture, and the price of forest products. An underlying ecosystem model assures that only regions consistent with natural forests are used for wood supply. The forestry program consequently does not entail any irrigation or water withdrawals. We assume that there is an international market for timber that leads to a global market clearing price. As the price of wood for bioenergy rises to compete with industrial timber, both timber and bioenergy will be traded internationally (Favero and Massetti 2014; Sedjo et al. 2015). Competition for supply will equilibrate prices across regions. We assume no uncertainty in these projections and that the market is forward looking: firms can predict future demand and supply and therefore future prices. Thus, GTM plants forests in advance of future wood demand whether for timber or biofuel.

The formal forest carbon sequestration program is assumed to rent carbon from forest owners at a rental price consistent with the carbon price path (Sohngen and Mendelsohn 2003). This allows the SEQU program to carefully optimize sequestration in each region of the world to match the actual tree growth and stock of trees in each place. Given the sheer amount of carbon stored above ground, SEQU is consequently quite expensive. Alternative schemes that both subsidize carbon during growth and tax carbon at harvest have also been suggested (van Kooten et al. 1995), but are not quite identical. Under the subsidy and tax scheme, the carbon value in the standing forest is a liability to an owner. With the rental scheme, the forest carbon is always an asset to a forest owner. The administrative costs of running this rental program are ignored. This may be a substantial omission in the case of forest sequestration. The complicated issues surrounding government-owned forestlands that are occupied by forest dwellers in many tropical countries are also ignored. We assume that each government acts in the best interest of its constituents.

Finally, to make WITCH and GTM consistent, several technical adjustments were made. The definitions of regions in the two models had to be matched: the 16 regions in GTM are aggregated to the 13 regions in WITCH. Second, the time steps had to be matched: the 10-year steps in GTM are broken down into two 5-year steps as in WITCH. Third, there are no terminal conditions in either model which distorts the results in the final periods. We consequently solve both models through 2150 in order to get appropriate results through 2100.

A detailed description of WITCH and GTM is provided in the Supplementary Material.

3 Results: WBCCS + SEQU

We start with a baseline scenario (BAU) with no mitigation which leads by 2100 to a level of GHG concentration in the atmosphere of 951 ppm, radiative forcing equal to 6.6 W/m^2, and a global temperature in 2100 of 4 °C above 1900 temperatures (Carraro et al. 2012). In the BAU scenario, global forestland remains somewhat constant over the century with a slight reduction from 3466 million ha in 2010 to 3229 million ha by the end of the century. Temperate regions would experience slight afforestation, and tropical regions would experience slight deforestation due to a small continued increase in global cropland.

We examine three price paths that lead to radiative forcing levels of 2.6, 3.6, and 4.5 W/m^2 as shown in Fig. 2. We first compare the outcome if only one forest mitigation option is available with the combined options under the highest carbon price scenario (2.6 W/m^2). WBCCS alone removes an average of 8.6 $GtCO_2$/year, SEQU alone removes 9.5 $GtCO_2$/year, and WBCCS + SEQU removes 14.5 $GtCO_2$/year over the 2020–2100 period studied (Table A1 in Supplementary Material). Given the same carbon price path, WBCCS + SEQU is more effective than either program alone.

By examining the mix of WBCCS and SEQU, we can determine the most effective mitigation role for forests depending on the circumstances. The results suggest that when carbon prices are low, forests are best used for sequestration (carbon storage). The size of the

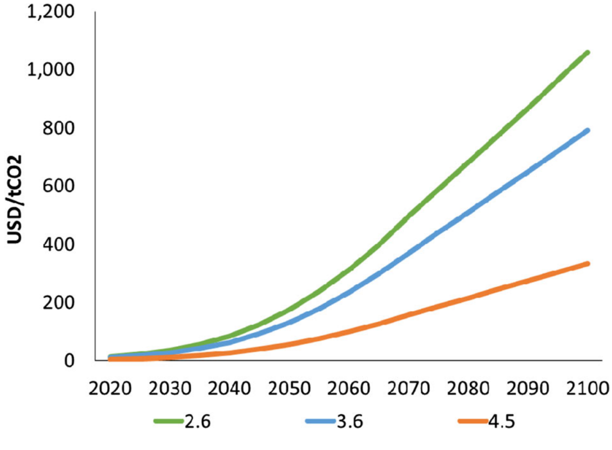


Fig. 2 Alternative carbon price paths by radiative forcing targets

forest increases and natural forests are favored over managed forests. However, when carbon prices are high, the relative value of using forests for biomass production increases. Forest size remains high but more of the forest will be devoted to production (rather than storage) and therefore will be managed.

The analysis reveals that forest mitigation is important. WBCCS + SEQU accounts for 908 $GtCO_2$ by the end of the century in the 4.5 W/m^2 scenario which is 23% of total mitigation. WBCCS + SEQU is even more important in the 2.6 W/m^2 scenario, removing 1290 $GtCO_2$ which is 26% of all mitigation. Forest mitigation plays a large role in a cost-effective greenhouse strategy.

SEQU is an important part of this forest mitigation strategy. With a moderate target of 4.5 W/m^2, SEQU does three fourths of the forest mitigation over the century. SEQU is effective at low carbon prices and so it dominates early forest mitigation. Even with a low initial global carbon price of 4–14 USD/tCO_2, there is sufficient incentive under SEQU to start sequestering carbon in forests in 2020 under all the climate mitigation policies tested. This is totally consistent with earlier results suggesting that carbon sequestration is effective at low carbon prices (Stavins 1999; Plantinga et al. 1999; Sohngen and Mendelsohn 2003).

In contrast, the carbon price needs to reach 125–230 USD/tCO_2 before the WBCCS portion of the program becomes feasible. Carbon prices do not reach this level until 2055–2065 depending on the stringency of the target (Fig. 3). WBCCS is particularly important with the 2.6 W/m^2 scenario, explaining half of cumulative forest mitigation (Fig. 4). WBCCS is critical in this scenario because most cost-effective plans involve overshooting the desired 2.6 W/m^2 target and then removing carbon from the atmosphere (Azar et al. 2010). Given current technology, WBCCS is the most effective tool at removing carbon dioxide from the atmosphere.

In general, the SEQU component of WBCCS + SEQU increases the stock of wood. The increase in long-term wood supply lowers the long-term price of wood compared to a scenario with only WBCCS (Fig. 1A in Supplementary Material). So, the wood product industry does far better under WBCCS + SEQU than WBCCS alone. In the long run, the lower price of wood is also helpful to WBCCS. Adding WBCCS, in turn, initially encourages more forestland than SEQU alone. So, the two forest-based mitigation programs tend to complement each other and this explains why they are so much more effective when used together. However, SEQU and WBCCS must compete for the same forestland in the latter half of the

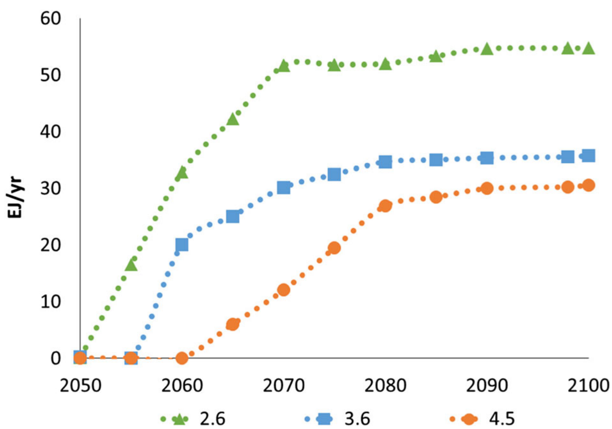
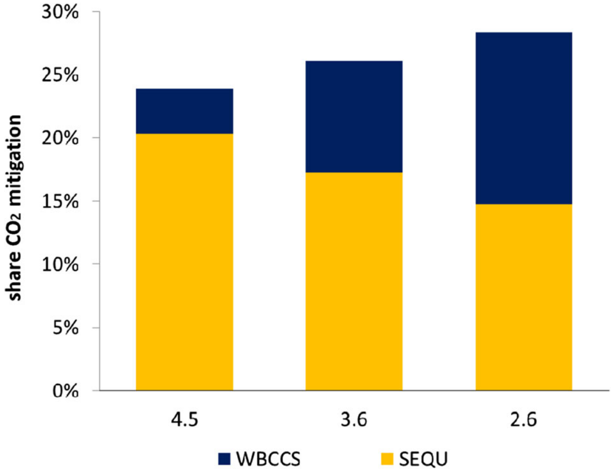


Fig. 3 WBCCS production under alternative radiative forcing targets

Fig. 4 CO_2 mitigation share of WBCCS and SEQU (2020–2100) under alternative radiative forcing targets



century. That is why the combined program of SEQU plus WBCCS leads to less mitigation than the sum of WBCCS alone and SEQU alone.

Table 1 shows how each component of the forest mitigation program contributes to removing carbon dioxide from the atmosphere relative to BAU. In the first half of the century, there is no biomass burning and the forest program is strictly a carbon sequestration program for all three climate policy scenarios tested. In 2055–2065, WBCCS begins operation. The additional aboveground carbon stored in trees is responsible for about 60% of the mitigation benefits from WBCCS + SEQU. The fraction of the total carbon removed by carbon stored underground by WBCCS and by fossil fuel substitution is about 29% in the 2.6 and 3.6 W/m^2 scenarios and 19% in the 4.5 W/m^2 scenario. The remaining benefits are from increased slash and forest soil carbon.

Figure 5 reveals what happens to managed and natural forestlands as a result of the WBCCS + SEQU program. Across all the mitigation policy scenarios, forestland expands

Table 1 Carbon removed from the atmosphere in 2050 and in 2100 under alternative radiative forcing targets relative to BAU

Scenarios	Carbon pools GtCO$_2$							Total CO$_2$ removal *(a + b + c + d + e + f)*
	Above ground *(a)*	Market[a] *(b)*	Soil *(c)*	Slash *(d)*	Total CO$_2$ removed from forest *(a + b + c + d)*	CCS *(e)*	Fossil fuel substitution *(f)*	
2.6 W/m^2								
2050	503	(21)	33	(105)	410	0	0	410
2100	711	(59)	104	151	908	218	164	1290
3.6 W/m^2								
2050	351	(9)	22	(65)	298	0	0	299
2100	602	(35)	78	93	737	165	128	1031
4.5 W/m^2								
2050	294	(4)	19	(54)	254	0	0	254
2100	629	(22)	70	60	736	95	77	908

[a] Market products from wood hold carbon

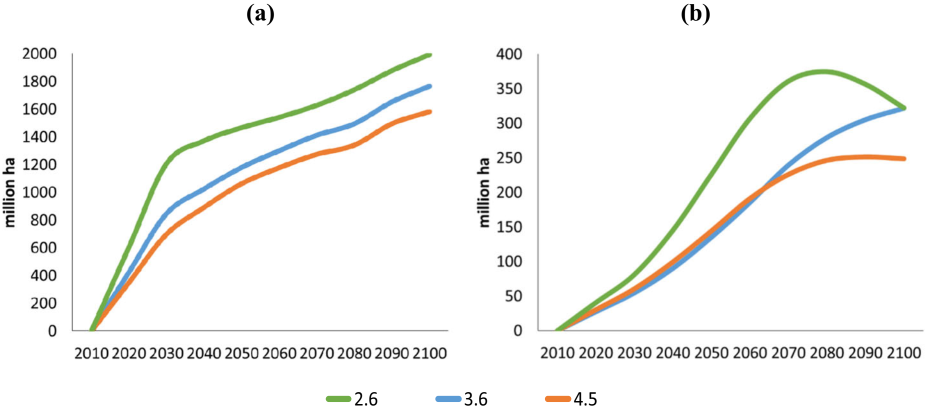


Fig. 5 Changes in **a** managed forestland and **b** natural forestland relative to BAU under alternative radiative forcing targets

dramatically. By 2100, there are 2.08 billion additional ha of forestland in the high price path scenario and 1.78 billion additional ha in the low price path scenario compared to BAU: 86% of this expansion is managed forestland in the 2.6 W/m^2 scenario and 80% in the 4.5 W/m^2 scenario. Natural forestlands do expand, but they reach a maximum size in 2080 with the 2.6 W/m^2 scenario and then start to shrink as WBCCS becomes far larger than SEQU and encourages ever more natural forestland to be converted to manage forestland. A similar phenomenon occurs with the less stringent climate policy scenarios at later dates. This 2 billion ha increase in forestland is consistent with the results from land use models (Humpenöder et al. 2014) who predict most of this forestland will come from pasture and just a small amount from cropland.

The effects of WBCCS + SEQU are not felt equally across all global forest types. For instance, in the high price scenario, tropical forests expand 1195 million ha, with three fourths of this in managed forestland by 2100. Temperate forests expand by almost 770 million ha and all of this is managed. Boreal forests expand by only 375 million ha and only 25 million ha of this is natural forest. The much larger response by tropical forests reflects the large amount of relatively low valued farmland that has replaced tropical forests in past decades and the relatively fast growth of many tropical forests. The stability of some tropical forests also makes them ideal storage forests. The much lower response by the boreal forest reflects its slower growth and the fact that only a small fraction of the boreal forest has ever been removed for farmland. The fact that all of the temperate and most of the boreal forestland has gone into management reflects that these forests are slow to grow to large sizes making them poor storage forests but reasonable sites for management.

Table 2 explains the regional contribution to the demand and supply of woody biomass and sequestration. The model equates global supply and demand for both bioenergy and sequestration. The regional supply (demand) in some regions exceeds the regional demand (supply) in which case they export (import). The exporters of sequestration credits are all tropical forest countries with Latin America and Asia (not China) contributing over half of the global supply of sequestration. Other-OECD, Russia, Europe, and North Africa-Middle East are regional importers. In contrast, the exporters of biomass are all temperate forest countries, with almost half of the wood for bioenergy production coming from Europe (30%) and the USA (20%). Other-OECD, Russia, Asia (not China), sub-Saharan Africa, and North Africa-Middle East are

Table 2 (a) Average annual regional production and consumption of SEQU and (b) cumulative regional production and consumption of WBCCS under the 2.6 W/m^2 target (2020–2100)

	USA	China	Latin America	Other-OECD	Russia	Europe	Asia (except China)	Sub-Saharan Africa	North Africa and Middle East
(a) Forest sequestration $GtCO_2$/year									
Supply	0.7	0.7	2.5	0.3	0.3	1.2	2.8	1.0	0.1
Demand	0.7	0.7	0.7	1.5	0.7	1.6	2.2	0.7	0.7
net[a]	(0.0)	0.0	1.8	(1.2)	(0.4)	(0.4)	0.6	0.3	(0.6)
(b) Woody biomass for WBCCS billion m^3									
Supply	4.9	3.7	2.4	3.0	1.6	6.8	1.9	0.4	0.0
Demand	1.9	1.8	2.0	3.5	1.9	3.5	5.6	2.3	2.2
net[a]	3.0	1.9	0.5	(0.5)	(0.4)	3.3	(3.7)	(1.9)	(2.1)

[a] Positive values imply excess supply (selling/exporting) and negative values imply insufficient domestic production (buying/importing)

importers. It may seem a surprise that other-OECD (Canada) and Russia are importers given their extensive boreal forests, but boreal forests have limited ability to generate supply. The model consequently implies a substantial amount of trade in both sequestration credits and biomass credits between regions. The trade could entail the actual movement of biomass but it would be a lot more efficient simply to move credits.

3.1 Sensitivity analysis

One of the startling predictions of the model is the rapid increase of forestland over the next century with a high carbon price path and WBCCS + SEQU. One question is whether there is enough potential forestland to accommodate such an increase. The answer from ecological models is that there once was 6 billion ha of forestland on earth (FAO 2012). Mankind has reduced this amount to the current 4 billion ha mostly by converting forest to farmland (and to a much lesser extent urban uses). The model includes a rising opportunity cost associated with converting ever more farmland back to forestland. Further, land use models tend to predict very similar effects (Humpenöder et al. 2014).

In order to understand what role land conversion plays in the results, we have done a sensitivity analysis where global forestland is restricted to its current level of 4 billion ha. Capping global forestland reduces the cumulative mitigation from WBCCS + SEQU from 1290 $GtCO_2$ by 2100 to only 650 $GtCO_2$ under the 2.6 W/m2 scenario. With forestland fixed, slightly more of the mitigation is from sequestration rather than WBCCS. One of the major advantages of WBCCS is its ability to increase the value of managed forestland relative to farmland and thus cause substantial land use conversion.

We have done a second sensitivity analysis to test the effect of using woody biomass in power plants without CCS (WB) as an additional mitigation option. Under the 2.6 W/m^2 scenario, WB starts in 2040, 10 years before WBCCS. By 2100, 19% of woody biomass burning would be for WB, with the remainder going to WBCCS. Adding WB to the mix, increases overall woody biomass burning by 10%, so WBCCS gets slightly smaller as WB increases. Adding WB increases costs slightly as global timber prices increase by 15%. Cumulative forest-based mitigation would increase by 5% by 2100 with WB included; therefore, adding WB as an alternative forest mitigation choice has only a small effect on overall mitigation.

4 Conclusion

This paper combines the global dynamic forest model (GTM) with the global mitigation model WITCH to study whether to use forestland for biomass burning or for carbon storage given alternative carbon price paths. The model determines the cost effective combination of both methods and shows the dynamics of woody biomass and forest carbon sequestration demand and supply over time. The strength of the analysis is the careful weighing of mitigation alternatives in WITCH along with a sophisticated model of forests in GTM. The model determines the desired amount of forestland in each scenario, the mix of managed versus natural forest, and how planting, rotation length, and management intensity should be adjusted on managed forestland. These decisions differ dramatically across the world's forests, and thus are critically important to include when modeling the role of forests in climate mitigation strategies.

Using these modeling tools, the study finds that if carbon prices are low, forests are best used for sequestration (carbon storage), but if carbon prices are high, the role of forests for biomass production becomes more important. Overall, adding WBCCS + SEQU encourages 2 billion ha of farmland to become forestland. More than half of this land would come from the tropics with temperate forests contributing most of the rest. Humpenöder et al. (2014) predict similar overall land use changes. They further predict that most of this new forestland would come from pasture.

The results in this paper show that WBCCS + SEQU can be used together to cost effectively remove about one fourth of all carbon mitigation. Sequestration builds an initial large forest supply that WBCCS later exploits. Combining WBCCS + SEQU reduces the price of wood relative to using only WBCCS. This is beneficial to both the wood product industry and WBCCS, lowering the price of wood in the second half of the century.

SEQU initially increases natural forestland. Later in the century, however, WBCCS manages most of this added natural forestland to supply energy. Tropical forests are more responsive to sequestration incentives and provide about 62% of the added forest sequestration. In contrast, temperate forests respond more vigorously to biomass burning and provide about 64% of the supply of woody biomass for energy.

The results strongly suggest that forest sequestration should be part of global mitigation efforts. Before this can occur, the world must design an effective sequestration program. There are institutional challenges to overcome (Mendelsohn et al. 2012). In many parts of the world, forest property rights are not well defined or belong to multiple owners. A cost-effective sequestration program needs to be global with a single carbon price. Inexpensive mechanisms to monitor forest carbon stocks need to be implemented. Finally, many sequestration programs assume additionality which implies public knowledge of business-as-usual forest management of every plot in the world which may be unrealistic (Andersson and Richards 2001; Richards and Stokes 2004; Andersson et al. 2009; Mason and Plantinga 2013).

Finally, there remain some important topics to study in this field. First, climate change effects on the growth of forests around the world and to fire risk could alter these results (Mendelsohn et al. 2016). Future research should integrate climate change effects into the decision to use forests to store carbon. Second, this study did not include the albedo effect of changing pasture into forestland (Jones et al. 2015; Kreidenweis et al. 2016). The fact that boreal forests do not change much in these scenarios may help moderate the magnitude of the albedo effect. Nonetheless, including albedo effects remains an important topic of future research.

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