U.S. DEPARTMENT OF
ENERGY

PNNL-19462

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Bioenergy and the importance of land use policy in a carbon-constrained world

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June 2010

Pacific Northwest
NATIONAL LABORATORY

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operated by
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under Contract DE-AC05-76RL01830

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(9/2003)

Title: Bioenergy and the importance of land use policy in a carbon-constrained world
Type: Paper
JEL Classification Code: Q54, Q42, Q24, Q58

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Abstract:

Policies aimed at limiting anthropogenic climate change would result in significant transformations of the energy and land-use systems. However, increasing the demand for bioenergy could have a tremendous impact on land use, and can result in land clearing and deforestation. Wise et al. (2009a,b) analyzed an idealized policy to limit the indirect land use change emissions from bioenergy. The policy, while effective, would be difficult, if not impossible, to implement in the real world. In this paper, we consider several different land use policies that deviate from this first-best, using the Joint Global Change Research Institute's Global Change Assessment Model (GCAM). Specifically, these new frameworks are (1) a policy that focuses on just the above-ground or vegetative terrestrial carbon rather than the total carbon, (2) policies that focus exclusively on incentivizing and protecting forestland, and (3) policies that apply an economic penalty on the use of biomass as a proxy to limit indirect land use change emissions. For each policy, we examine its impact on land use, land-use change emissions, atmospheric CO_2 concentrations, agricultural supply, and food prices.

INTRODUCTION

Policies aimed at limiting anthropogenic climate change would result in significant transformations of the energy and land-use systems. Several studies have shown that these transformations would involve a significant increase in the production and consumption of bioenergy (IPCC AR4 2007; Clarke et al., 2007; Edmonds, et al 2007; Pacala and Socolow 2003; Hoffert et al., 2002). Bioenergy is an attractive fuel source because it can be combusted for heat and power or transformed into liquid fuels much like fossil fuels. Unlike fossil fuel sources, however, bioenergy is a net zero emissions source where emissions associated with combustion are offset by the emissions uptake associated with growing the bioenergy. Bioenergy links the energy system to the agricultural and terrestrial system. Increasing the demand for bioenergy could have a tremendous impact on land use, and can result in land clearing and deforestation. Recently, significant attention has focused on these indirect effects of bioenergy on agriculture, land use, and land-use change emissions (Wise et al., 2009a,b; Edmonds et al., 2003; Fargione et al., 2008; Searchinger, et al., 2008; Schmer, et al., 2008; Gillingham et al., 2008).

Most of this literature has focused on identifying and quantifying the indirect land use change (ILUC) effect. Wise et al. (2009a,b) analyzed one policy that limited the ILUC effect. However, this is an idealized policy that subsidizes land owners based on the carbon content[1] of their land. The policy, while effective, would be difficult, if not impossible, to implement in the real world. In this paper, we consider several different land use policies that deviate from the first-best solution discussed in Wise et al. (2009a,b). For each policy, we examine its impact on land use, land-use change emissions, and atmospheric CO_2 concentrations.[2]

In the first policy framework, we subsidize land owners for their above ground carbon only. Under this policy, land types with large above ground carbon stocks (e.g., forests) are preferable to those with smaller above ground carbon stocks (e.g., grass and shrub land). Our results suggest that while this change in incentives has an impact on land cover and land-use change, it has little effect on CO_2 concentrations relative to the first best scenario.

The second type of policy framework focuses on forests. First, we model a carbon subsidy like the first-best policy but applied only to forests. Second, we consider an approach to forests that is similar to the United Nations Reducing Emissions from Deforestation and Forest Degradation (REDD) policy. In this policy, we protect forest lands by removing them from the economic competition. Any land removed from competition cannot be cleared for bioenergy or other crops. Our results suggest that a significant amount of forest cover must be protected to have a significant impact on deforestation, land-use change emissions, and CO_2 concentrations.

The third policy framework we consider places a tax on bioenergy but does not value the carbon in the terrestrial system. Our results suggest that CO_2 concentration is non-monotonic in the level of the bioenergy tax. Low bioenergy taxes result in large deployments of bioenergy (which reduces energy system emissions) and widespread deforestation (which increases land-use change emissions). High bioenergy taxes effectively ban bioenergy (which increases land-use change emissions) and prevent deforestation (which reduces land-use change emissions).

MODEL DESCRIPTION AND SCENARIO DESIGN

All of the scenarios described in this paper use the Global Change Assessment Model (GCAM). The GCAM model (Kim et al., 2006, Clarke, et al., 2007b, Brenkert et al. 2003), formerly known as MiniCAM, is a dynamic-recursive model, linking a global energy-economy-agricultural-land-use model with a suite of coupled gas-cycle, climate, and ice-melt models integrated in the Model for the Assessment of Greenhouse-Gas Induced Climate Change (MAGICC). The model is a descendent of a model developed by Edmonds and Reilly (1985) and has been used extensively by the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency, the Intergovernmental Panel on Climate Change (IPCC), and other

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[1] Both above and below ground carbon are considered in this subsidy.

[2] It should be noted that in this paper, we have applied the same time path of carbon values to various policy frameworks, and we have compared the resulting CO_2 emissions from the energy and terrestrial systems and the end of the century atmospheric CO_2 concentrations for each framework. This measure does provide an internally consistent indication of the relative economic efficiency of each policy in achieving a given concentration target. However, note that although differences in concentrations may appear small relative to the total concentration in the UCT case, achieving these differences requires major changes in emissions. It is likely that the relative differences in costs of these policies may be much greater than the relative differences in concentrations shown here.

government, private and non-governmental organizations for energy, climate, and other environmental. Documentation for GCAM can be found at http://www.globalchange.umd.edu/models/gcam/.

The GCAM model operates on a 15-year time step from 1990 through 2095. At each time step, the model solves for market-clearing prices for all energy, agricultural, and land markets such that supply and demand for each market balances.

GCAM explicitly models the production, transformation, and consumption of energy. The supply of depletable energy resources (e.g., fossil fuels and uranium) are derived from resource curves. Their production depends on the amount of each grade available and the cost of extraction. Renewable resources, like wind and solar, are produced from graded resource bases. The supply of bioenergy depends on the availability of land, the productivity of the land, the technologies available for production, and the competing land use options. Primary energy sources can be consumed directly or transformed into liquid fuels, electricity, or hydrogen. The demand for energy is driven by the need to meet service demands in the buildings, industry, and transport sectors.

The GCAM model has a fully integrated agriculture, land use and land cover module that determines the supply and demand of agricultural products. Thus, the model can link the imposition of a climate policy to the demand for bioenergy and the changes in land cover needed to produce that bioenergy. Land allocation in each region is determined assuming that farmer’s maximize profits, where profits depend on the productivity of the land, the price of the product, and the non-land costs of production (labor, capital, fertilizer, etc.). However, we assume that there is a distribution of profit rates for each land type across each GCAM region. Thus, all land within each region is not allocated to the land type with the highest expected profit (as it would be in a “winner take all” competition). Instead, the amount of land allocated to a given type is equal to the probability that land type has the highest profit in that region. A more complete description of the agriculture and land use component of GCAM can be found in Wise et al. (2009a).

A full description of GCAM and the current demographic, economic, resource, and technology assumptions are provided in Clarke et al. (2008), accessible at http://www.pnl.gov/science/pdf/PNNL18075.pdf.

REFERENCE SCENARIO

For this analysis, we use a reference scenario based on the one developed for the U.S. Climate Change Science Program (Clarke et al., 2007). This scenario is characterized by a global population that grows steadily for the next 50+ years, peaking at 9 billion people in 2065 before beginning to slowly decline (Figure 1, Panel A). Global gross domestic product (GDP) increases from $40 trillion in 2005 to nearly $350 trillion in 2095 (Figure 1, Panel A). This grows results in a significant expansion of the global energy system. Primary energy increases from approximately 450 EJ per year in 2005 to over 1400 EJ per year in 2095 (Figure 1, Panel

B). The energy system continues to be dominated by fossil fuels despite significant growth in the production and use of nuclear and renewable energy.

Cropland in the reference scenario expands to feed a growing population that demands more meat and dairy as incomes increase (Figure 1, Panel C), with this expansion tempered by assumed increases in crop productivity. Production of dedicated bioenergy crops begins in the early part of the century. This bioenergy competes with coal, gas, and oil to supply liquid fuels and electricity. The result of the expansion of cropland and bioenergy land is a decline in forest land cover.

As a result of increasing energy consumption and the use of fossil fuels, global energy and industrial CO_2 emissions continue to increase, growing to nearly 80 $GtCO_2$/yr in 2095 (Figure 1, Panel D). Land use change emissions remain positive for the first half of the century before declining towards zero in the second half of the century. Total anthropogenic CO_2 emissions are dominated by energy system emissions throughout the century.

BENCHMARK CASES: PERFECT LAND USE POLICY & NO LAND USE POLICY

The introduction of a climate policy changes the dynamics of the energy system. Demand for carbon intensive fuels decreases, and demand for low carbon and carbon-free energy sources increases. This dynamic increases demand for bioenergy, which can have significant consequences on agriculture and land use. Wise et al. (2009) explored the impact of bioenergy on land use and land-use change emissions under two different policy regimes. For this analysis, we implement these two policy regimes under a single fixed CO_2 price path (Figure 2). This price path assumes that the carbon is first priced in 2020 at a value of approximately \$10/tCO_2. The price then rises at 5% per year for the rest of the century. We use this same price path for all policy environments explored in this paper.

The first policy regime, the fossil fuel & industrial carbon tax (FFICT) regime, placed a carbon policy on energy and industrial emissions only. The imposition of a price on carbon emissions in the energy system results in increased demand for bioenergy. As a result, bioenergy land increases significantly at the expense of forest cover (Figure 3, Panel A). This deforestation trend results in a significant increase in land-use change emissions (Figure 4, Panel A).

The second policy regime, the universal carbon tax (UCT), imposed a price on land-use change emissions equal to the price on energy and industrial emissions. Placing a value on carbon in land provides incentives to increase carbon stocks. As a result, global forest land expands (Figure 3, Panel B). This expansion limits the amount of land devoted to bioenergy production. In addition, cropland begins to decline. The decrease in cropland is due to both declines in meat consumption relative to the reference and increases in the efficiency of food production. Crop production shifts to more productive regions, increasing the global average yield, and reducing the amount of land required for food production. These changes in land cover result in a decrease in land-use change emissions relative to both 2005 and the reference scenario (Figure 4, Panel A). The differences in land-use change emissions between the two policy regimes amounts to a difference in CO_2 concentrations of nearly 90 ppmv in 2095 (Figure 4, Panel B).[3]

ALTERNATIVE POLICY ENVIRONMENTS

Much of the policy discussion today concerns reducing deforestation and promoting afforestation due to the tremendous amount of carbon stored in forest. Thus, for the first two policy frameworks examined here, we focus on vegetation carbon. In the first, we subsidize land owners for their above ground carbon only. This small change from the Wise et al. (2009a,b) framework changes the incentives for different types of land. Shrub land and grass land have a tremendous amount of below ground carbon, but very little carbon stored above ground. When land owners are subsidized for both types of carbon, there are incentives to keep grass land and shrub land. However, when only above ground carbon is valued, these incentives do not exist. Instead, grass land and shrub land are converted to other land types to allow for more growth in forests (Figure 5, Panel A). In this framework, grass land in 2095 is 25% smaller than in the first-best case and shrub land is 65% smaller. This difference in land cover causes a 50% increase in cumulative land-use change emissions between 2005 and 2095 over the first-best case (Figure 6, Panel A), but this increase is still small in absolute terms and relative to global fossil fuel and industrial emissions. Thus, this policy results in an increase in CO_2 concentrations in 2095 of less than 5 ppmv (Figure 6, Panel B) over the first-best case.

The second type of policies we study here focus exclusively on forests. In our first forest policy, we focus on reducing deforestation and promoting afforestation by subsidizing forest carbon only. Thus, the policy essentially rewards land owners for growing trees, but places a zero value on all other forms of terrestrial carbon. With this policy, there are strong incentives to convert land to forests and thus, forest land cover more than doubles between 2005 and 2095 (Figure 5, Panel B). This increase in forest causes a destruction of grass and shrub land, both of which store large amounts of carbon in their root systems. In order to plant trees on this land, these root systems will be disturbed, releasing carbon into the atmosphere. This effect, combined with the long lead time for carbon accumulation in forests, results in an increase in land-use change emissions in 2020 relative to both the first-best case and the reference scenario (Figure 6, Panel A). By the end of the century, the expanded forest begins to uptake more and more carbon driving land-use change emissions towards zero, but the emissions in the early part of the century are enough to drive CO_2 concentrations up from the first-best value. Thus, in 2095, CO_2 concentrations in the forest subsidy only case are approximately 514 ppmv, larger than the 480 ppmv in the perfect land policy case (UCT), but lower than the 570 ppmv in the no land policy case (FFICT).

Both of the policies just discussed, where either above-ground carbon is subsidized or juts forest carbon is subsidized, require measuring and monitoring of global land cover and carbon stocks, as well as large transfers of money to subsidize land owners for their carbon. Both are simplifications from the original perfect land use policy in the Wise et al. (2009) paper, but these policies would also be difficult to implement in the real world. For that reason, we

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[3] In the Wise et al. (2009) paper, the authors adjusted the CO_2 price to ensure CO_2 concentrations were equal in the two policy regimes. In this paper, we keep the CO_2 price path the same, but compare differences in CO_2 concentrations.

consider a second type of forest policy that does not require measuring of carbon stocks or subsidies. This policy framework is similar to the United Nations Reducing Emissions from Deforestation and Forest Degradation (REDD) policy. In this policy, we protect forest lands by removing them from the economic competition. Any land removed from competition cannot be cleared for bioenergy or other crops. This policy differs from the forest carbon subsidy policy in that it aims to reduce deforestation only, but provides no incentives for afforestation. The results suggest that a significant amount of forest cover must be protected to have a significant impact on deforestation, land-use change emissions, and CO_2 concentrations. In each of the four levels of protection considered (10% of forest land, 50%, 90%, and 95%), demand for low carbon and carbon free energy results in the conversion of a significant amount of land to bioenergy land (Figure 7). Under scenarios where little forest land is protected, this bioenergy land results in widespread deforestation and the release of large amounts of CO_2 into the atmosphere (Figure 8, Panel A). In the scenarios with a significant amount of forest land protected, bioenergy crowds out pasture, grass lands, and shrub lands. The destruction of these land types also releases CO_2 into the atmosphere. However, a significant amount of the land-use change emissions in these cases are offset by reduction in emissions in the energy system. As a result, when 95% of forest land is protected, CO_2 concentrations are only 19 ppmv higher than in the perfect land policy scenario (Figure 8, Panel B). As we reduce the fraction of forest land protected, CO_2 concentrations increase. Thus, when 50% of forest land is protected, CO_2 concentrations in 2095 are approximately half-way between the concentrations in the perfect land policy scenario and the no land policy scenario. When only 10% of forest land is protected, CO_2 concentrations are reduced from the no land policy scenario by a mere 8 ppmv.

The third and final type of policy framework we consider here places a tax on bioenergy but does not value the carbon in the terrestrial system. We explore four different bioenergy tax levels, starting between \$0.09/GJ and \$0.47/GJ in 2020 and growing at a 5% interest rate (Figure 9). For low bioenergy taxes, the value of bioenergy outweighs the cost of the tax and bioenergy demand is similar to the no land policy case (Figure 10). This results in wide-spread deforestation and significant land-use change emissions. When the tax on bioenergy is large, bioenergy use is effectively banned. While a ban on bioenergy prevents land-use change emissions, the loss of a biomass option results in significantly higher energy-system emissions (Figure 11, Panel A). In general, we find that increasing the bioenergy tax rate increases energy system emissions, but decreases land-use change emissions. The combination of these effects produces a non-monotonic relationship between the bioenergy tax rate and cumulative total anthropogenic emissions (Figure 11, Panel A). As a result, CO_2 concentrations in 2095 are non-monotonic in the bioenergy tax rate (Figure 11, Panel B). This suggests that there is some range of levels of bioenergy use that is preferable to the ban on bioenergy resulting from high bioenergy taxes and to over-use of bioenergy and the resulting deforestation that occurs under low bioenergy taxes. However, the bioenergy tax policy does not provide an efficient signal about how much and where the biomass should be grown. Additionally, a bioenergy tax provides no incentives for afforestation. As a result, the 2095 CO_2 concentration in all of the bioenergy tax scenarios exceeds the CO_2 concentration in the perfect land policy scenario by at least 50 ppmv.

DISCUSSION

The results and implications from even a simple set of scenarios as studied here can quickly become complicated. However, there are some clear conclusions that can be drawn. One result is that a policy that subsidizes just above ground carbon is nearly as effective as a first best policy, which subsidizes both above and below ground carbon. However, such a policy will be almost as difficult to implement and enforce as the first best policy.

A second result is that a policy that only values carbon in forest lands is not effective, and potentially counterproductive, as it provides a strong incentive to clear shrub lands and pastures which have substantial below ground stores of carbon. On the other hand, a policy that protects forests, much like national parks, may be effective in limiting land use emissions, but only if most of the world's forests are protected. The conclusion drawn from the final scenario is that a policy that simply taxes bioenergy provides no incentives other than to limit or even eliminate bioenergy. Doing so will remove the problem of indirect land use emissions from bioenergy, but it provides no incentives to increase the carbon stock in land. And just as important, eliminating bioenergy removes a potentially valuable mitigation option in the energy system, increasing the cost of achieving a climate goal.

Finally, in this paper we have explored each of these policy frameworks in the context of complete global cooperation. Further work will need to assess the degree of land-use leakage induced by a climate policy when it is imposed on only a subset of the world's regions, and how that leakage would vary by the type of policy framework.

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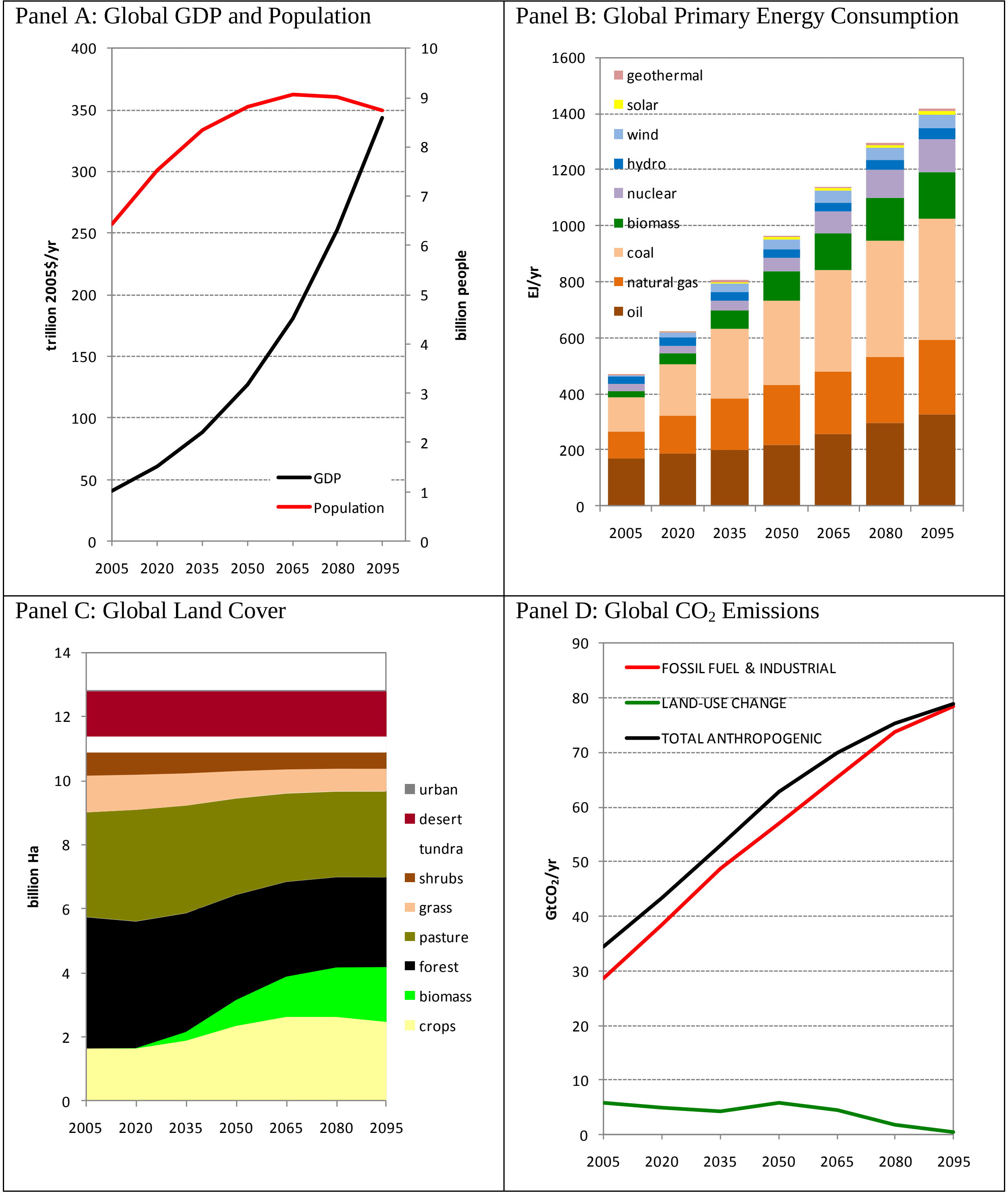
Figure 1: The Reference Scenario


Panel A: Global GDP and Population

Panel B: Global Primary Energy Consumption

Panel C: Global Land Cover

Panel D: Global CO_2 Emissions

Figure 2: CO_2 Price Path

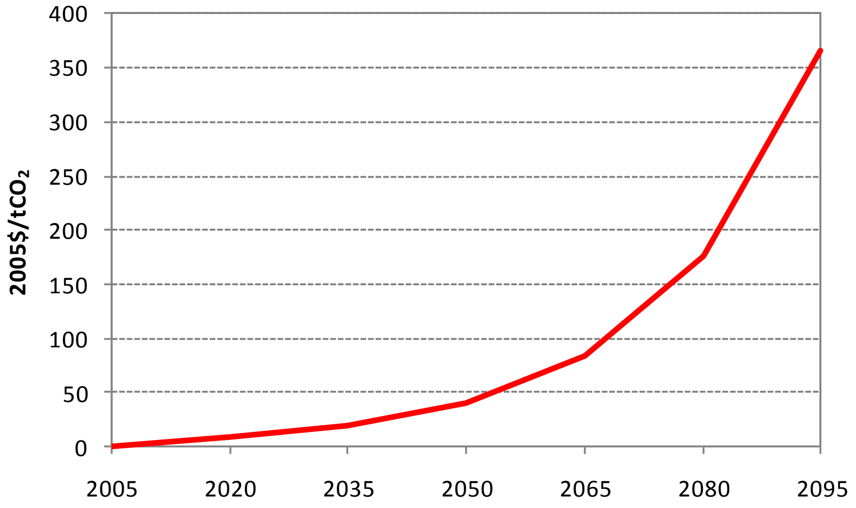
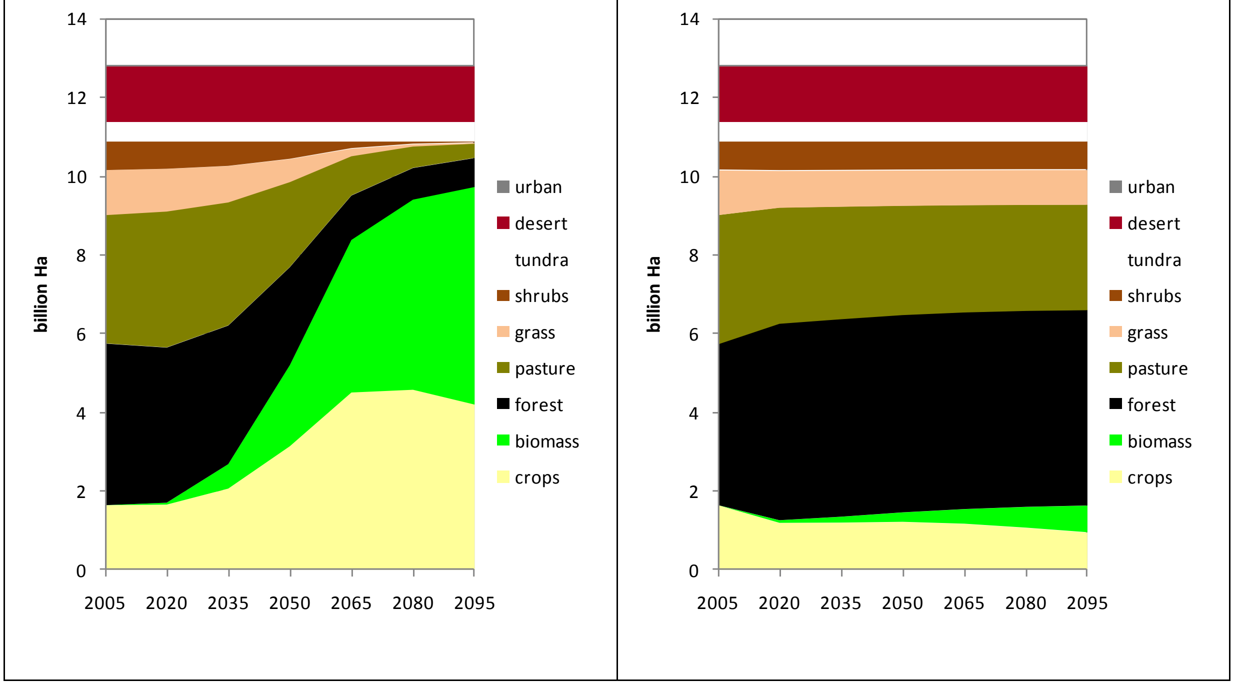
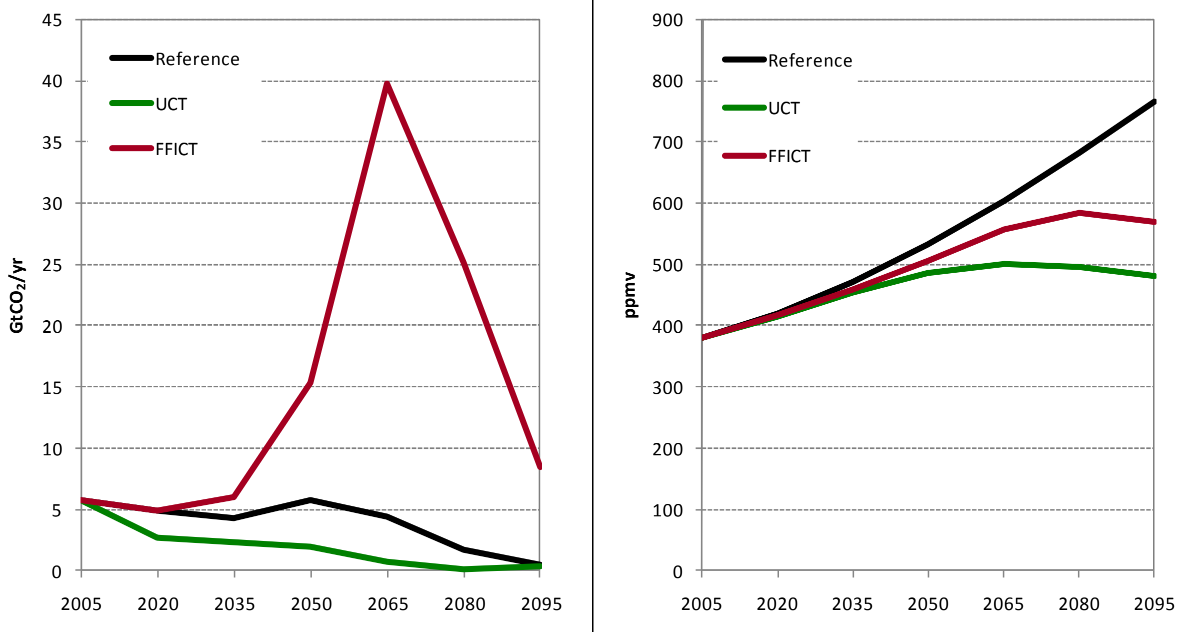


Figure 3: Global Land Cover in Two Benchmark Cases


Panel A: No Land Policy (FFICT)

Panel B: Perfect Land Policy (UCT)

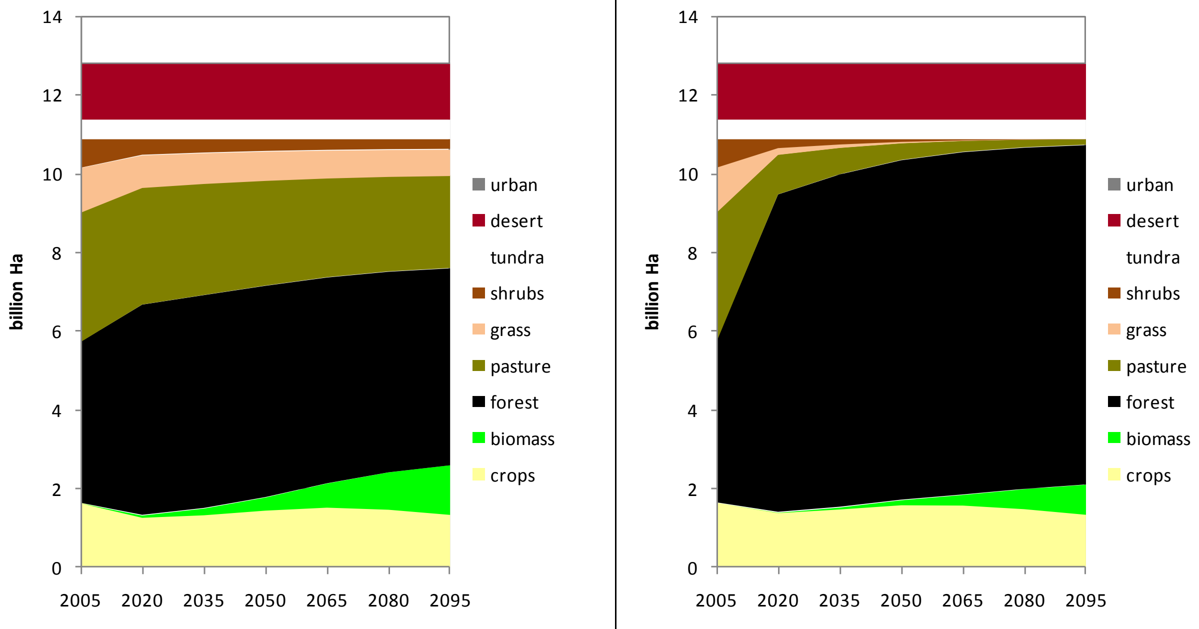
Figure 4: Global Land-Use Change Emissions and Global CO_2 Concentrations



Panel A: Global Land-Use Change Emissions

Panel B: Global CO_2 Concentrations

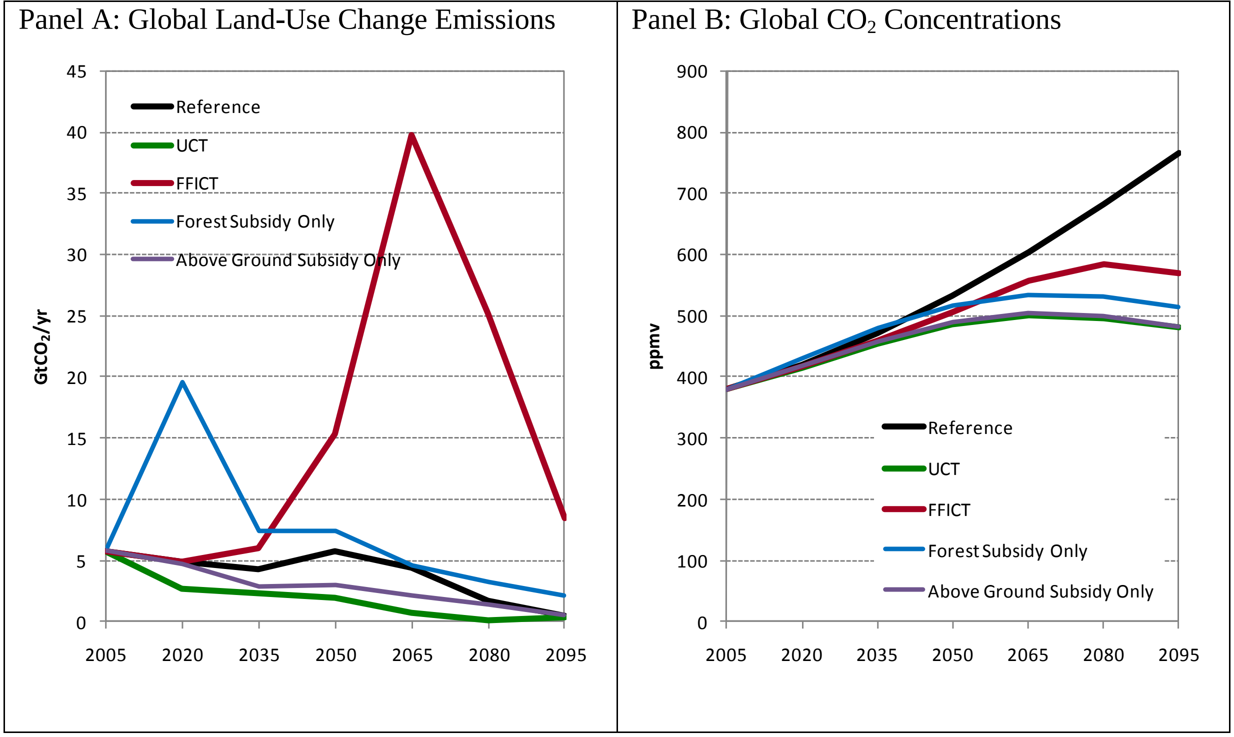
Figure 5: Land Cover for the Vegetation Carbon Policies



Panel A: Only Above Ground Carbon is Subsidized

Panel B: Only Forest Carbon is Subsidized

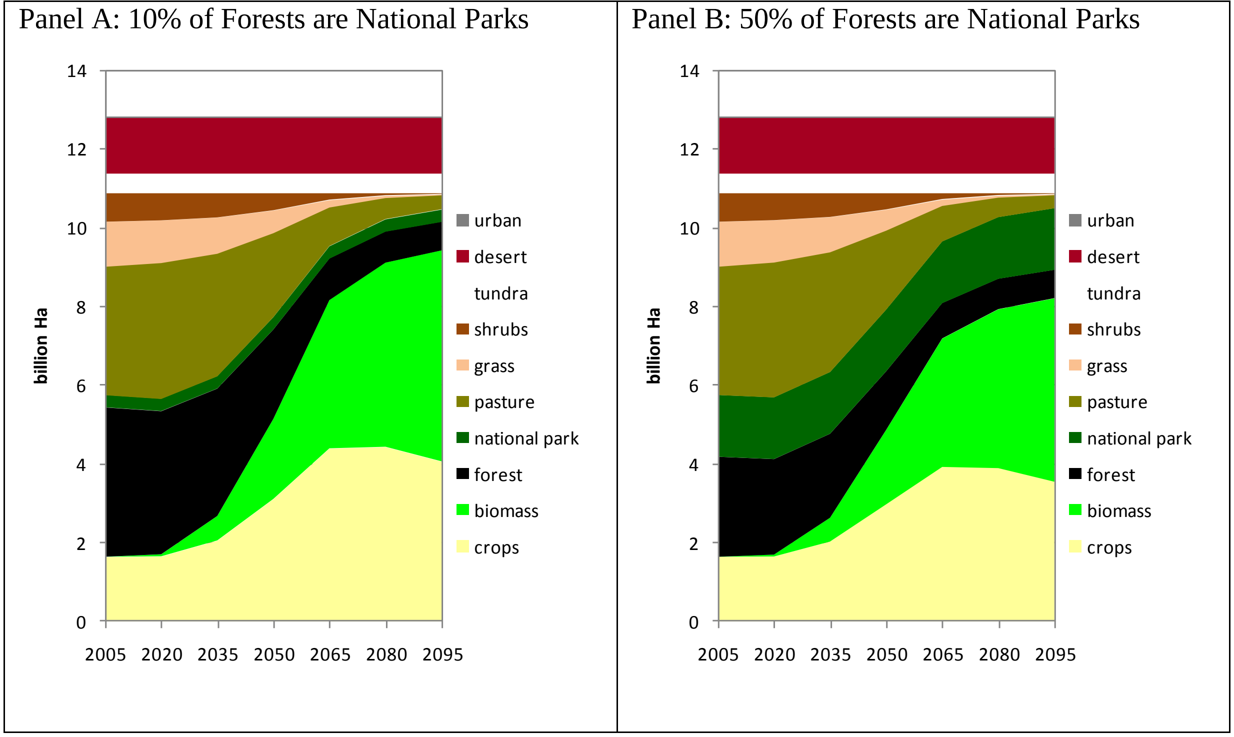
Figure 6: Land-Use Change Emissions and CO_2 Concentrations in the Vegetation Carbon Policies



Panel A: Global Land-Use Change Emissions

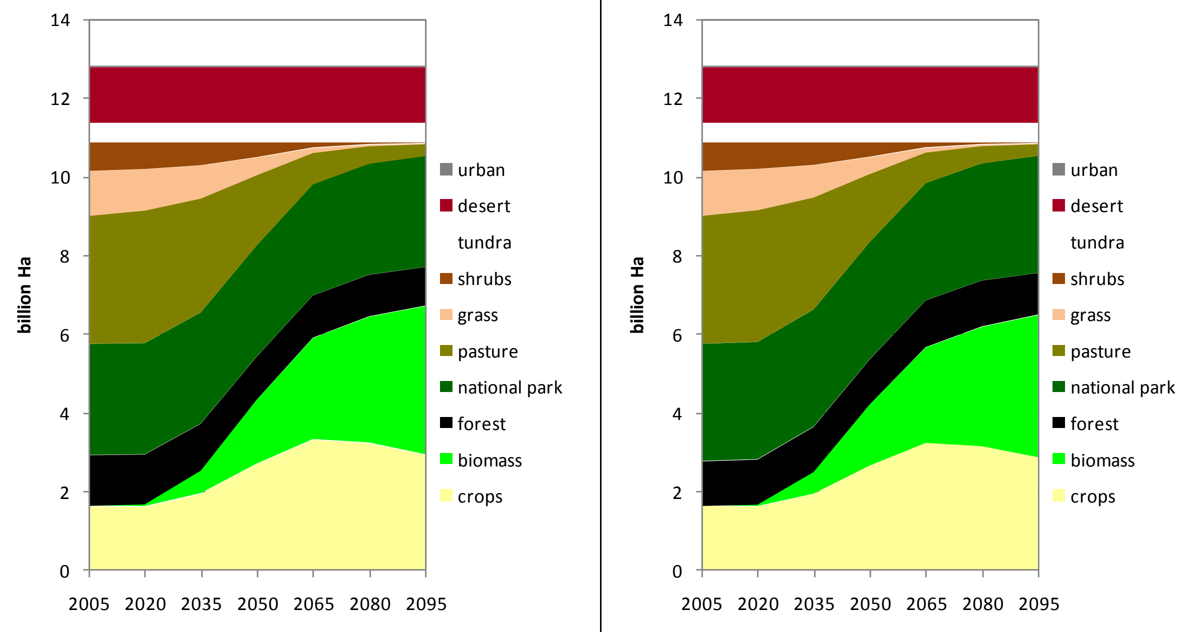
Panel B: Global CO_2 Concentrations

Figure 7: Land Cover in the Four National Park Scenarios



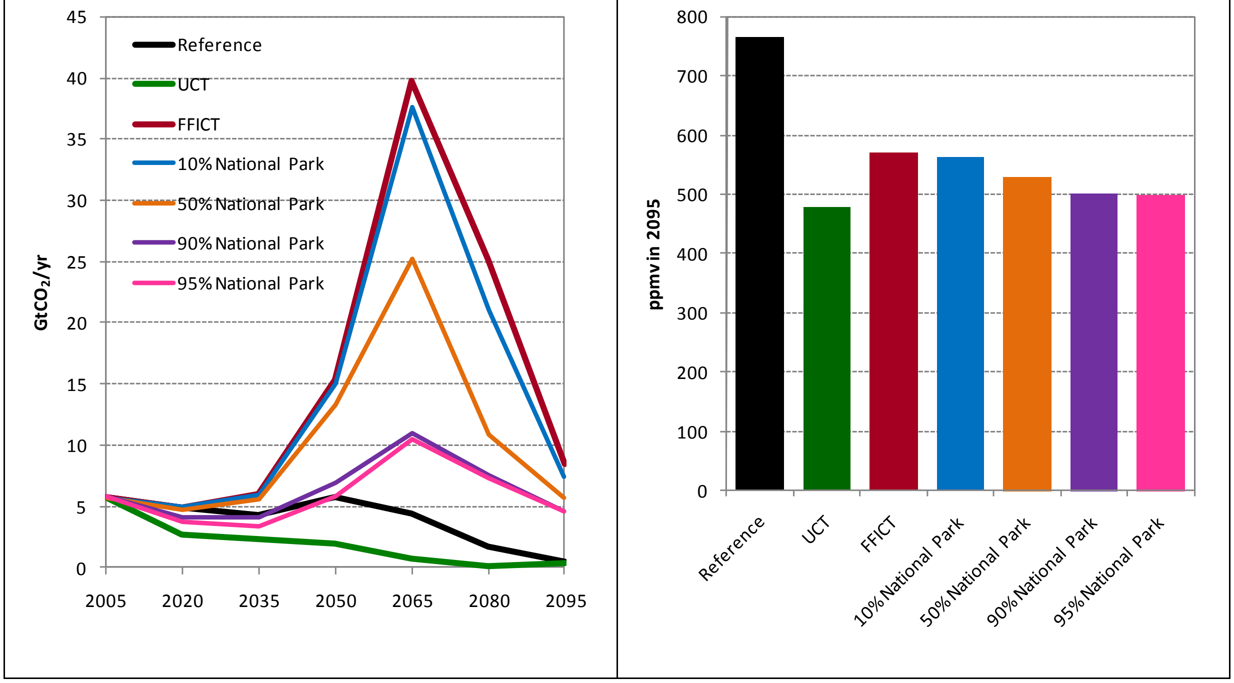
Panel A: 10% of Forests are National Parks

Panel B: 50% of Forests are National Parks


Panel C: 90% of Forests are National Parks

Panel D: 95% of Forests are National Parks

Figure 8: Land-Use Change Emissions and CO_2 Concentrations in the National Park Scenarios


Panel A: Global Land-Use Change Emissions

Panel B: Global CO_2 Concentration in 2095

Figure 9: Bioenergy Tax Levels

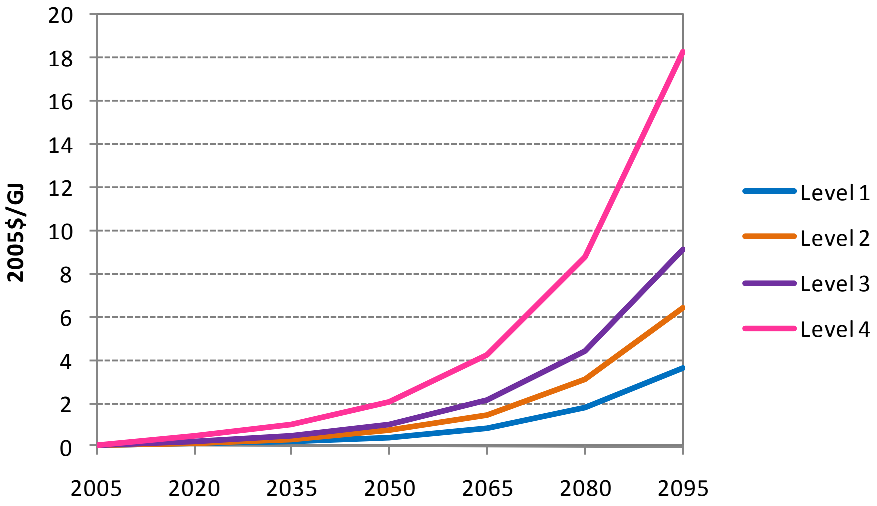


Figure 10: Global Bioenergy Consumption in the Biomass Tax Scenarios

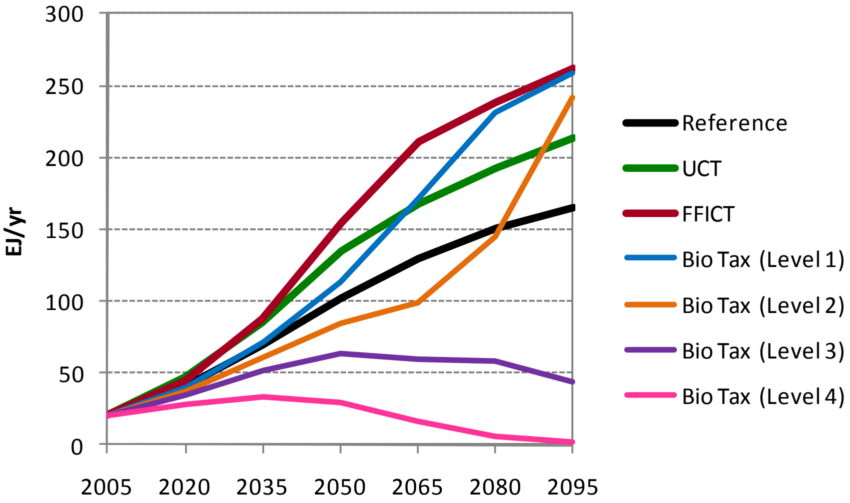
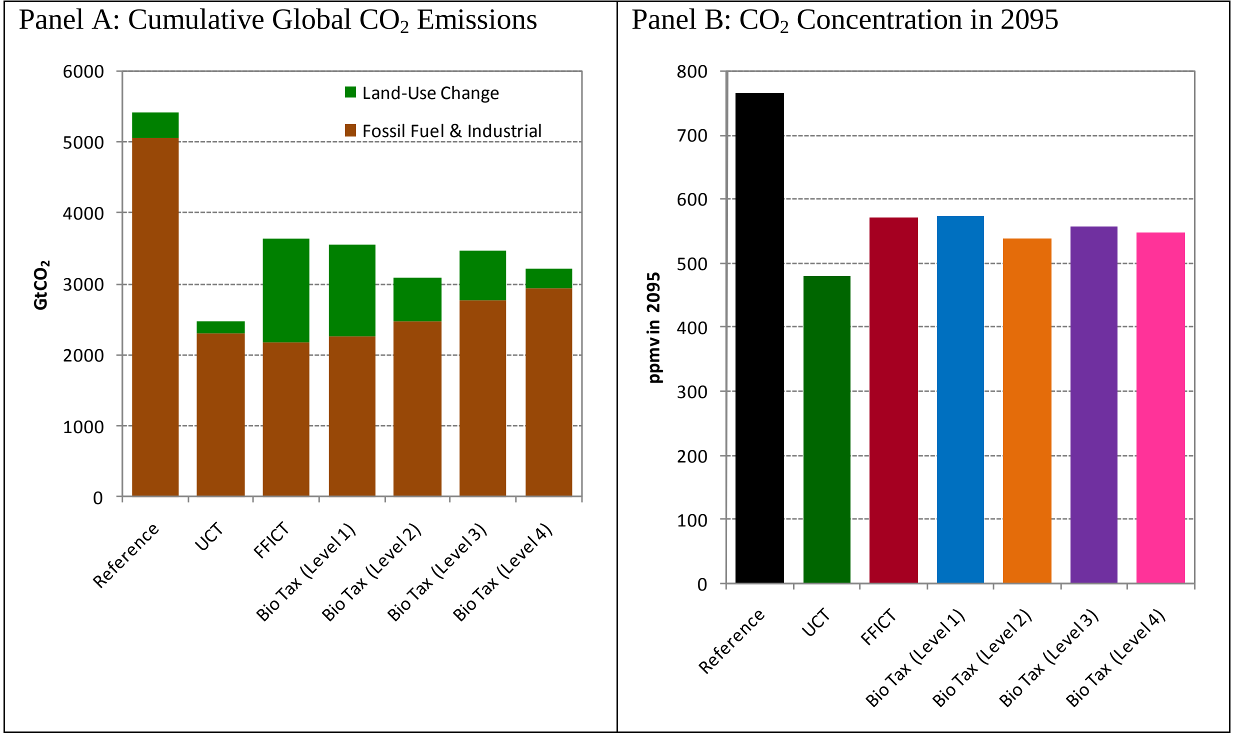


Figure 11: Cumulative CO_2 Emissions and CO_2 Concentrations in the Biomass Tax Scenarios



Panel A: Cumulative Global CO_2 Emissions

Panel B: CO_2 Concentration in 2095