Food, Fuel, Forests and the Pricing of Ecosystem Services

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Abstract

We investigate how demand for alternative ecosystem services, as agricultural and biofuels production, recreation and carbon storage, may be complementary or competitive. We also assess how pricing of all of new services may affect land use, food prices, and the prospects for biofuels production. We expand the Emissions Prediction and Policy Analysis (EPPA) model, a recursive dynamic general equilibrium model of the world economy, to explicitly represents the recreation value of ecosystems, formulated through the expansion of traditional economic accounts to represent outdoor recreation services used by the household. We also extend this model to represent the carbon storage value of alternative ecosystem services. Another innovation introduced in the model is to be able to price carbon uptake or emissions from land use change. We consider the decision to invest in biofuels as a dynamic problem, since the land use changes needed to produce biomass result in an initial carbon debt that is eventually repaid through repeated harvests that continue to offset fossil fuel use. We simulate several experiments, considering CO_2 prices on fossil fuel use, land use emissions and credits for carbon uptake from land use changes. We find that growth in demand for biofuels increases with implementation of CO_2 pricing policies and that leads to increased CO_2 emissions from land use conversion if CO_2 prices only cover energy emissions and are not extended to emissions from land. If we extend CO_2 pricing to land use emissions that provides sufficient economic incentive to avoid most of the deforestation that would otherwise occur. If we further extend CO_2 pricing to provide credits for increasing the stock of carbon we find significant reforestation such that globally land use becomes a large net sink for CO_2, with a substantial increase in CO_2 storage in vegetation and soils at the expense of other land uses, especially pasture and grazing. Our analysis suggests that land transitions occurring over the century if CO_2 storage is credited would eventually store CO_2 equal to as much as a third the entire global energy emissions over this coming century assuming these emissions are controlled by climate policy. With at least two new large non-food demands for land (CO_2 storage and biofuels) that compete with land for food the need to assure that low income households worldwide have food or the resources to afford it becomes critical. Finally, we simulate scenarios where different coalitions of countries impose policies penalizing land use emissions and crediting land use uptakes to investigate whether leakage is an important phenomenon in land use emissions.

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1. Introduction

Concern about degradation of natural resources has led in the ecological community to the concept of “ecosystem services.” The intent is to identify more fully what environmental economists would refer to as “use-values” of ecosystems, concrete good and services that have value, albeit perhaps unrecognized, to the market economy as opposed to “non-use values” such as the pleasure of knowing that a natural system exists. The ecological community has also coined the term “agroecosystems” recognizing that agricultural lands are, albeit modified through management, ecological systems. As such, conventional food and forest products are the product of ecosystems. Biofuels may be another important ecosystem service. Conventional economic analysis can be applied because these are goods that enter markets in the conventional sense.

The values of other ecosystem services are not so explicit in economic data. Here we extend an economic model to explicitly represent the recreation value of ecosystems and their carbon storage value. Our interest is how demand for these various ecosystem services may be complementary or competitive and how pricing of all of new services may affect land use, food prices, and the prospects for biofuels production.

2. Method

We apply a computable general equilibrium (CGE) model of the world economy, the Emissions Prediction and Policy Analysis (EPPA) model, augmented to consider land use and land-use change shown in Table 1 as described in Gurgel, Reilly and Paltsev (2007).

Economic data are from the Global Trade Analysis Project (GTAP) (Dimaranan and McDougall 2002). We develop supplemental accounts to track physical energy use, emissions, and land use change, a crucial step in relating expenditure data, the entries in social accounting matrices that are the basis for CGE models, to environmental outcomes (see Paltsev et al. 2005). We expand traditional economic accounts to represent demand for hunting, fishing, and wildlife viewing (Antoine, Gurgel and Reilly 2008). To do this we create household production activities *a la* Becker (1981) where household time (leisure) is combined with other goods and forest land to produce outdoor recreation services used by the household. Data on expenditures on hunting, fishing, and wildlife viewing and to maintain public parks and recreational areas for the US are available (US Census Bureau 2000). We use a benefits transfer approach for other regions, scaling the outdoor recreation services sectors to the recreation sector in GTAP to equal the share of these sectors of the US recreation sector in each region. Here we further extend that work by pricing carbon uptake or emissions from land use change.

The size and complexity of the EPPA model as formulated here forecloses solving it as a fully dynamic model. However, as shown for somewhat simplified and shortened horizon version of the model, the differences in many results of interest from solving the model recursively or dynamically are minor (Babiker et al. 2009). For example, banking and borrowing of emissions allowances, in principle requiring dynamic optimization, can be simulated by imposing the theoretical result that their price rise at the discount rate.

We deal with fundamental dynamic nature of forest carbon accounting in the recursive structure by observing that for a hectare of land:

(1) $$CarbV_{i \to j,k} = \sum_{t=k}^{m} \frac{P_{C,k}(1+\gamma)^t Carb_t}{(1+r)^t}$$

where *CarbV* is the net present value of the change in carbon stock for a hectare of land transition from use i to j at time k, $P_{C,k}$ is the price of carbon at time k, γ is the rate of increase in the price of carbon, r is the discount rate, $Carb_t$ is the carbon flux from or to the land at time t, and M is the number of years to an equilibrium stock level of carbon after the land use change. Observing that with banking and borrowing of allowances γ=r and that for the recursive model we require the annualized rate of return (1) reduces to:

(2) $$annualizedCarbV_{i \to j,k} = (r+\delta)P_{C,k}Carb_T$$

where the annualized return is a rental rate, consisting of the discount rate (plus δ) times the price of carbon in year k times the integrated change in the carbon stock from transition i to j here labeled $Carb_T$, where δ=1/M. We obtain values of $Carb_T$ by comparing average carbon stocks (soil plus vegetation) for land per unit area in different uses derived from the Terrestrial Ecosystem Model (TEM) for each EPPA region, as estimated by Melillo et al. (2009) (Table 2). In general, pasture land has the lowest carbon stock, natural grass land the next lowest, then cropland and managed forest and finally natural forest. We assume protected and non-protected natural forest has the same carbon stock. We can then impose a system of carbon credits for uptake, or require purchase of allowances for transitions that lower carbon stocks. For values of M we use data from Sohngen et al. (2009) and Sohngen (2009) on optimal rotation length for forest harvest and assume full maturation, when carbon stocks reach maximum, is twice the optimal rotation length.

We further observe that the decision to invest in biofuels is a dynamic problem because the land use changes needed to produce biomass result in an initial carbon debt that is eventually repaid through repeated harvests that continue to offset fossil fuel use (Melillo et al 2009). We compare the value of emissions from using a hectare of land indefinitely to produce biofuel crops to the value of fossil fuel emissions it would replace:

(3) $$\sum_{t=k}^{\infty} \frac{P_{C,k}(1+\gamma)^t * (BiofuelEmissions_t)/(1+r)^t}{P_{C,k}(1+\gamma)^t * GasCarb_t/(1+r)^t} = \theta$$

where *GasCarb* are emissions from gasoline, and we identify this ratio as θ. This simplifies to:

(4) $$\sum_{t=k}^{\infty} \frac{(BiofuelEmissions_t)}{GasCarb_t} = \theta$$

The initial carbon debt means the net effect of biofuels is negative in early years ($BiofuelEmissions_t > GasCarb_t$) but as emissions fall $BiofuelEmissions_t < GasCarb_t$. Melillo et al. (2009) demonstrate that direct and indirect land use emissions go to zero in the long run as decomposition of organic matter comes into equilibrium with the residual vegetation left for decomposition, but they are left with an indefinite flow of N_2O emissions related to fertilizer use. In CO_2 equivalent the annual N_2O emissions associated with biofuels produced on one hectare are 21% of the emissions from the fossil fuel it replaces, and we observe that as *t* tends to infinity the ratio in equation (3) goes to long run ratio. Thus, with the combination of banking and borrowing with future discounting the investor should ignore the cost of the initial carbon debt. However, by crediting or costing carbon from land transitions that cost is built into land used for biofuels. To correct for this we create credits for biofuels production equal to (1-θ) per GJ of biofuel used. In a functioning market, where agents were looking forward these credits would be unnecessary, but given the recursive model structure we need to introduce them to generate a solution consistent with forward-looking behavior.

3. Policy Simulations and Results

We consider the simulation experiments in Table 3. These include a no policy Reference case, a case with a $10/ton CO_2 price that rises at 4% per year, a case extending the cap to land use emissions but designed to achieve the same CO_2 price, and a case that further creates incentives for CO_2 sequestration on land. The degree to which it is possible to further intensify conventional production will affect how much land is available for new demand for recreation, biofuels, and augmentation of CO_2 stored in land, and it will affect prices of all of these goods. In the EPPA model, ability to intensify production is controlled primarily by two substitution elasticities in the crop and livestock production nests. The elasticity, σ_{ER} is the substitution between energy/materials and land, and σ_{EVRA} is the substitution between the energy/materials/land input bundle and value added bundle that combines capital and labor (Paltsev, et al., 2005). In the high elasticity case these are 0.6 and 0.7, respectively. In the low elasticity case these are 0.3 and 0.35. Higher prices for land can be overcome by substituting in the lower nest toward energy, fertilizer, and other materials, and in the upper nest toward capital and labor. Higher prices for energy or energy-intensive inputs (fertilizer, pesticides) resulting from the CO_2 pricing of energy emissions will limit substitution toward these goods from land, and force more of the substitution to occur toward capital and labor.

Table 4 displays some of the key results. The pricing of CO_2 and other GHGs (omitting CO_2 from land use change) reduces cumulative energy-emissions over the century by nearly two-thirds (from about 7,000 Gt to about 3,200 Gt). The high and low elasticity cases, as expected, mostly affect land use and land emissions. Note that given our convention of considering the infinite horizon for land use change, the emissions and sequestration amounts are an estimate of the infinite horizon change in soil and vegetation carbon of land use transitions that occur during the century. Moreover, the approach spreads use of the allowances beyond the 2100 period through implicit banking.

In the reference, with the high elasticity case land emissions and sequestration nearly balance so that land is a small net sink of just 36 Gt of CO_2. With the low elasticity, land emissions rise and sequestration falls so that land becomes a net source of of 291 Gt over the century. Net land use emissions fall slightly in the *Energy CTax* case, the result of a rise in both emissions and sequestration. As seen in Figure 1, biofuels are produced at the expense of all other land uses but especially of pasture and forests. Conversion of unmanaged forest land leads to carbon loss, but use of pasture leads to a carbon gain and thus the effects are offsetting. Note also that even in the reference case there is substantial biofuels production by 2100. However, the policy case leads to earlier biofuels production and by 2100 about 170 EJ more than without the policy. In both policy and reference biofuels production is about 100 EJ less with the low elasticities.

Including land use emissions under the cap greatly reduces land emissions so that land as a whole is a more significant net sink on the order of 360 Gt (High elasticity) or 190 Gt (Low elasticity). Energy emissions increase slightly because less biofuels are produced leading to less reduction in petroleum use but that increase is only 100 to 220 Gt. By creating an incentive for CO_2 sequestration on land over time, because of the land use changes spurred by this incentive, the cumulative CO_2 stock on land would be about 660 (low elasticity) to 1045 Gt (high elasticity) greater, as much as a third of the energy-related emissions over the century. As noted previously our infinite horizon assumption implies some of these extra tons are banked for future periods.

The land use changes show that with sequestration crediting, starting immediately once the policy is in place, there is a shift of land use to natural forest area. The “shock” to land use change occurs because, as the policy is specified, land owners worldwide go from a situation where carbon sequestration in land has no value, to one where they see a long run value to storing CO_2. The reduction in land use for conventional purposes, especially in the high elasticity case, is quite substantial and to make such a change would likely require advances in crops and production practices. However, looking this far into the future the potential for significant land-augmenting technical change needs to be considered. For example, Carolan, Joshi and Dale (2007) and Laser et al. (2009) describe bioprocessing refineries that could produce multiple products including feedgrain equivalent livestock feed, ethanol, and other biochemicals from a general biomass stock. Such a process would greatly increase the economic productivity of land by producing feedgrain equivalent products, using the entire plant rather than just the grain and using a wide range of biomass feedstocks with different climatic tolerances thus dramatically expanding the climate range suitable for producing "feedgrains." The greatly reduced land for pasture could be accomplished by a move to confined livestock operations worldwide, and implicitly a shift to poultry and away from more land intensive beef, for example.

Behind these land use changes, and partly explaining them, are changes in the prices of conventional agricultural products (Figure 2). Crop and livestock prices rise from the *Reference* case to the *Energy CTax* case, rise higher in the *Energy + LUC CTax*, and rise higher still in the *Energy + LUC CTax & CCRED*. Prices increase considerably more in the low elasticity case. The most extreme increase is for livestock prices in *Energy + LUC CTax & CCRED* with low elasticities. Prices nearly triple compared with current prices for livestock. The rise in livestock prices reduces demand for livestock, which in turn reduces the demand for feedgrains. The reduction in feedgrain demand lessens the impact on crop prices. Still crop prices rise by 60% in this case. Food prices, while not shown here, rise by about the same amount as crop prices. The food price increase is less that the average of crop and livestock price increases because other production costs that are not rising are added into the food price.

As shown earlier, significant biofuels production is entering even in the reference scenario. Under the high elasticity *Reference* case, livestock and crops prices remain nearly flat. But in the low elasticity case the pressure is enough to lead to significant price increases of nearly 20% for crops and over 60% for livestock. With the climate policy there is additional demand for land for biofuels and the energy cost and the cost of controlling methane and N_2O from agricultural activities adds substantially to the crop and livestock cost. The additional crop and livestock price increase in moving to the *LUC* emissions tax is less than might be expected because the CO_2 price is unchanged and so there are no further increases in the price of energy (and energy intensive agricultural inputs such as fertilizer and chemicals). In the *CCRED* cases the land use shift is quite large and it is not surprising to see large increases in crop and livestock prices. Forest product prices, while not shown, rise even more because the land cost is a larger fraction of the product price.

Crop and livestock prices can be quite variable and the increases projected here are generally less than the sometime several fold increase that can be seen over a couple of years. So are these large? Comparing against variability in prices is misleading in our view, as an increase that lasts for just a year or two is far different than a persistent trend. The better comparison is with the long term trend in food and commodity prices, which has shown a general decline over time. Compared with that, a persistent and substantial increase in prices over the century is a substantial change.

Next we test alternative coalitions of countries applying the Energy and LUC Ctax and Ccred policy, considering the low elasticity assumption. It allows to access if a limited coverage of countries under a land use change emissions policy would significantly decrease the effectiveness of the policy through leakage. The results are displayed in Table 5. To allow a better comparison, we reproduce the results from the Reference scenario and Energy and LUC Ctax and Ccred case (global coalition) from Table 4 in the first and second columns of Table 5.

Starting at the third column, we show the alternative coalition schemes applying the carbon tax on energy and land use changes together with the carbon credits on sequestration from land use changes. The limited coverage of such policies would greatly reduce the effectiveness of the policy, depending on the region left out of the coalition. Land emissions would be higher than in the reference case if only developed countries and the former soviet union apply the carbon policies. However Biofuels production is greater in this scenario than when the global policy is applied only to fossil fuel emissions (Energy Ctax case in Table 4). It shows how biofuels is associeated with higher land use emissions and the trade-offs between land carbon sequestration and bioenergy, since the regions which most contribute to biofuels production (AFR and LAM) are left out of the coalition.

The most important geopolitical region of the world affecting land use emissions is Latin America, which includes the EPPA regions LAM and MEX, since their inclusion in the coalition drops most of the emissions. As discussed above, the biofuels output also drops when LAM applies the full carbon policy on land. FSU is the most effective region influencing carbon sequestration from land use changes, although land use changes in all developed countries alone would be able to sequester more than half of the carbon sequestered under the global coalition. A coalition between developed countries and Africa would have little impact in reducing land emissions, since biofuels production from Latin America would keep contributing to increase such emissions.

Among the scenarios simulated, a full policy on land use changes, including carbon taxes for emissions and subsidies for sequestration, will generate net sequestration only if Latin America adopts the policy, unless a broader group of regions, as FSU and Asia (China, India, Indonesia) applies the policy together with developed countries. If the coalition includes FSU, Asia (China, India, Indonesia) and Latin America, but excludes AFR, ASI and ROW, the net land use emissions would represent a carbon sink of around 310 Gt of CO2, what is less than half the carbon sink from a policy of global coverage on land use emissions.

Fossil fuel emissions don't change considerably under the alternative coalition schemes, since the carbon policy on those emissions is the same in all scenarios. However, leakage on land use emissions seems considerable. It varies between 348 Gt of CO_2-e, when some few regions (AFR, ASI and ROW) do not apply the carbon policy on land, and 873 Gt of CO_2-e when only developed countries do it. The leakage represents between 14% and 34% of total cumulative emissions if we could add cumulative net land use and fossil emissions.

4. Discussion and Conclusions

We find that growth in demand for biofuels increases with implementation of CO_2 pricing policies and that leads to increased CO_2 emissions from land use conversion if CO_2 prices only cover energy emissions and are not extended to emissions from land. If we extend CO_2 pricing to land use emissions that provides sufficient economic incentive to avoid most of the deforestation that would otherwise occur. If we further extend CO_2 pricing to provide credits for increasing the stock of carbon we find significant reforestation such that globally land use becomes a large net sink for CO_2. In this situation land use positive effect on the carbon balance by storing carbon in forests and through providing a biofuels that offset CO_2 emissions from gasoline use. We find that pricing carbon emissions from land use and further crediting uptake of CO_2 when forests are regrown does not substantially reduce the amount of biofuels produced.

The effect of full pricing of carbon in land use transitions is a substantial increase in CO_2 storage in vegetation and soils at the expense of other land uses, especially pasture and grazing. Our analysis suggests that land transitions occurring over the century if CO_2 storage is credited would eventually store CO_2 equal to as much as a third the entire global energy emissions over this coming century assuming these emissions are controlled by climate policy. This changes considerably the view of where the CO_2 problem and its solution exist. Many analysts look at current emissions and see land use emissions as 20% of total emissions. Further they see land emissions as perhaps constant or even falling in the future while energy-related emissions may triple over the century. Focusing on emissions in this way suggests the CO_2 problem is mostly a fossil energy problem and much attention on a solution has focused on reducing those emissions. But focusing only on emissions from land use ignores the potential for not only reducing them but also enhancing land sinks.

Pricing CO_2 in land-use transitions is complementary with some land uses and competing with others. At one end, recreational demand for forests is highly complementary with CO_2 storage because forests can provide recreational services while also storing CO_2. At the other extreme, pasture and grazing competes strongly with CO_2 storage potential, as these improved and degraded grasslands have some of the lowest CO_2 storage. Cropping (biofuels and conventional crops) lies in between because management of land (i.e. additional fertilization) can improve CO_2 storage compared with use of the land for grazing and pasture, but CO_2 storage on cropland is considerable less than in an undisturbed forest. In the scenarios with full CO_2 pricing we see both substantial reforestation and substantial biofuels production, and because of the relative CO2 storage considerations the impact is especially strong on the livestock sector. We see substantial increases commodity prices and especially in livestock prices which together contribute to an increase in food prices. This implies some difficult policy tradeoffs. In the absence of adequate food programs poor consumers could suffer substantially from higher food prices. With at least two new large non-food demands for land (CO_2 storage and biofuels) that compete with land for food, the need to assure that low income households worldwide have food, or the resources to afford food, is critical.

A key issue is how responsive agricultural technology is to rising land prices. We represent this by way of elasticities of substitution between land and purchased inputs (energy, fertilizer, seeds, etc.) and these inputs and capital and labor. We considered cases with low elasticities and high elasticities although in both cases substitution was inelastic (less than 1.0). The main difference in these two cases was the effect on food prices, with the lower elasticity case resulting in higher food prices. While the food price effects were less with the high elasticities the resulting increases are still a substantial departure from the historical trend of falling food prices. Attention both to overall development especially in lagging regions and food security programs in all regions is needed as we face new demands for land stemming from an expanded view of ecosystem services.

An interesting final aspect we have explored has to do with the possibility of leakage if only some regions apply the policy on land use emissions. It reaffirms the trade-off between biofuels production and carbon sequestration from land, as also reveals which regions may most contribute as carbon sinks. The total cumulative leakage can vary from only 14% if only some few regions are left out of a global carbon coalition to reduce emissions from land use, to 34% when developed countries are the only ones pricing carbon from land use changes.

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Table 1. Regions, Sectors, and Primary Factors in the EPPA Model

Country or Region	Sectors	Factors
Developed	***Non-Energy***	Capital
United States (USA)	Services (SERV)	Labor
Canada (CAN)	Energy-Intensive (EINT)	***Energy Resources***
Japan (JPN)	Other Industries (OTHR)	Crude Oil
European Union+ (EUR)	Commercial Transp. (TRAN)	Natural Gas
Australia/N.Zealand (ANZ)	*Household Production*	Coal
Former Soviet Union (FSU)	Household Transp. (HTRN)	Oil Shale
Eastern Europe (EET)	Hunting and Fishing (REHF)	Nuclear
Developing	Wildlife Viewing in Reserves (REWV_R)	Hydro
India (IND)	Other Wildlife Viewing (REWV_N)	Wind/Solar
China (CHN)	***Fuels***	***Land***
Indonesia (IDZ)	Coal (COAL)	Cropland
Higher Inc. East Asia (ASI)	Crude Oil (OIL)	Pastureland
Mexico (MEX)	Refined Oil (ROIL)	Managed Forest
Centr. & S. America (LAM)	Natural Gas (GAS)	Non-Reserved Natural Forest
Middle East (MES)	Oil from Shale (SYNO)	Reserved Natural Forest
Africa (AFR)	Synthetic Gas (SYNG)	Natural Grassland
Rest of World (ROW)	Liquids from Biomass (B-OIL)	Other
	Electricity Generation	
	Fossil (ELEC)	
	Hydro (HYDR)	
	Nuclear (NUCL)	
	Solar and Wind (SOLW)	
	Biomass (BIOM)	
	Coal with CCS (IGCAP)	
	Adv. gas without CCS (NGCC)	
	Gas with CCS (NGCAP)	
	Agriculture	
	Crops (CROP)	
	Livestock (LIVE)	
	Forest products (FORS)	
	Food Processing (FOOD)	

Table 2. Carbon stocks above and below ground (tons C/ha)

	Pasture	Cropland	Managed Forest	Natural Grass	Non-protected Natural Forest	Protected Natural Forest
USA	43.70	76.46	94.91	76.73	94.99	94.99
CAN	67.12	163.43	116.91	94.90	180.39	180.39
MEX	32.57	75.72	41.00	39.42	58.39	58.39
JPN	72.66	90.29	97.67	0.00	211.47	211.47
ANZ	24.92	76.92	19.91	39.42	38.32	38.32
EUR	55.93	89.33	93.05	73.99	167.27	167.27
EET	55.85	85.50	81.28	62.08	185.82	185.82
FSU	33.43	115.22	106.15	108.22	137.18	137.18
ASI	58.98	89.56	81.65	46.81	303.22	303.22
CHN	50.61	73.64	104.34	83.87	62.90	62.90
IND	41.73	48.75	65.21	47.39	165.90	165.90
IDZ	57.01	96.39	83.05	93.72	327.16	327.16
AFR	24.50	63.40	34.81	30.78	124.81	124.81
MES	9.29	34.78	17.57	17.70	13.25	13.25
LAM	50.51	94.55	71.76	109.34	221.43	221.43
ROW	35.37	65.04	45.99	47.95	187.39	187.39

Source: Melillo, et al. (2009)

Table 3. Scenarios

SCENARIO		DESCRIPTION
REFERENCE	High Substitution	No climate policy, continued economic growth, land productivity growth of 1% per year, recreation demand for land. See: Antoine, et al. (2008).
	Low Substitution	
ENERGY CTAX	High Substitution	Worldwide common GHG tax applied to all GHG emissions except CO_2 emissions from land use change, starting at \$10/tCO_2, rising at 4%/yr
	Low Substitution	
ENERGY +LUC CTAX	High Substitution	GHG tax extended to include emissions from land use change, but not credits for increased land uptake
	Low Substitution	
ENERGY+LUC CTAX & CCRED	High Substitution	Tradable credits are available for land transitions that increase carbon compared with existing use, which can be used to in lieu of the GHG tax.
	Low Substitution	

Table 4. World Cumulative Emissions, CO_2 Prices and Biofuels Production

	Reference		Energy Ctax		Energy and LUC Ctax		Energy and LUC Ctax and Ccred	
	High Elast.	Low Elast.	High Elast.	Low Elast.	High Elast.	Low Elast.	High Elast.	Low Elast.
Cumulative Land Emissions 2015-∞ (Gt CO_2)	287	511	418	626	12	13	12	13
Cumulative Land Sequestration 2015-∞ (Gt CO_2)	323	220	467	361	368	200	1057	670
Cumulative Net Land Emissions 2015-∞ (Gt CO_2)	-36	291	-49	265	-356	-187	-1045	-657
Cumulative Fossil Emissions 2015-2100 (Gt CO_2-e)	7117	7081	3130	3221	3232	3440	3106	3220
CO_2 Price 2015 ($/ton CO_2e)			10	10	10	10	10	10
CO_2 Price 2050 ($/ton CO_2e)			39	39	39	39	39	39
CO_2 Price 2100 ($/ton CO_2e)			280	280	280	280	280	280
Biofuels Output 2030 (EJ)			10	8	10	6	51	41
Biofuels Output 2050 (EJ)	36	27	71	60	66	40	118	73
Biofuels Output 2100 (EJ)	252	167	425	326	352	192	288	200

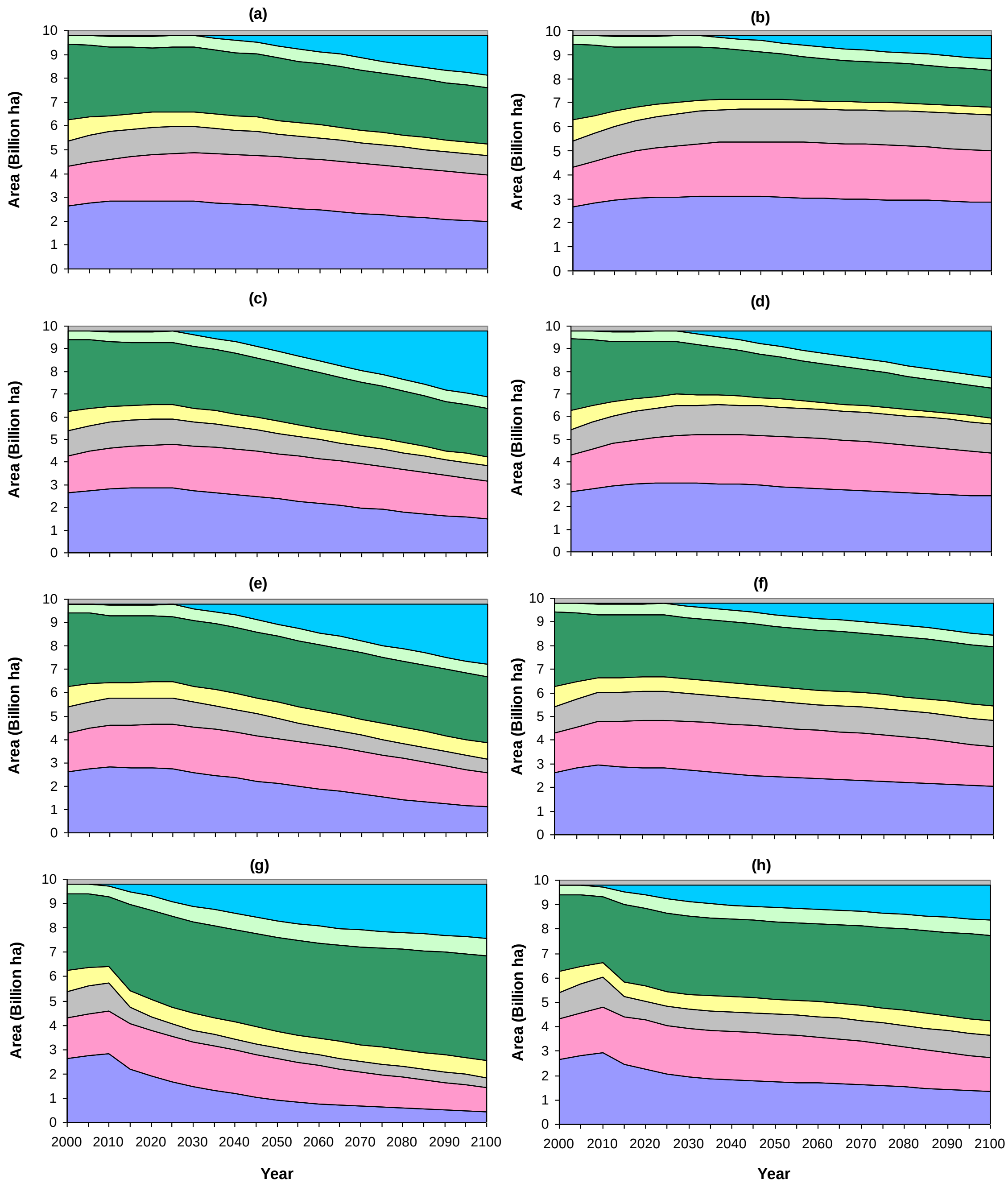

Figure 1. Land use changes: *Reference* high elasticity (a) and low elasticity (b); *Energy ctax* high elasticity (c) and low elasticity (d); *Energy +luc ctax* high elasticity (e) and low elasticity (f); *Energy+luc ctax & ccred* high elasticity (g) and low elasticity (h).

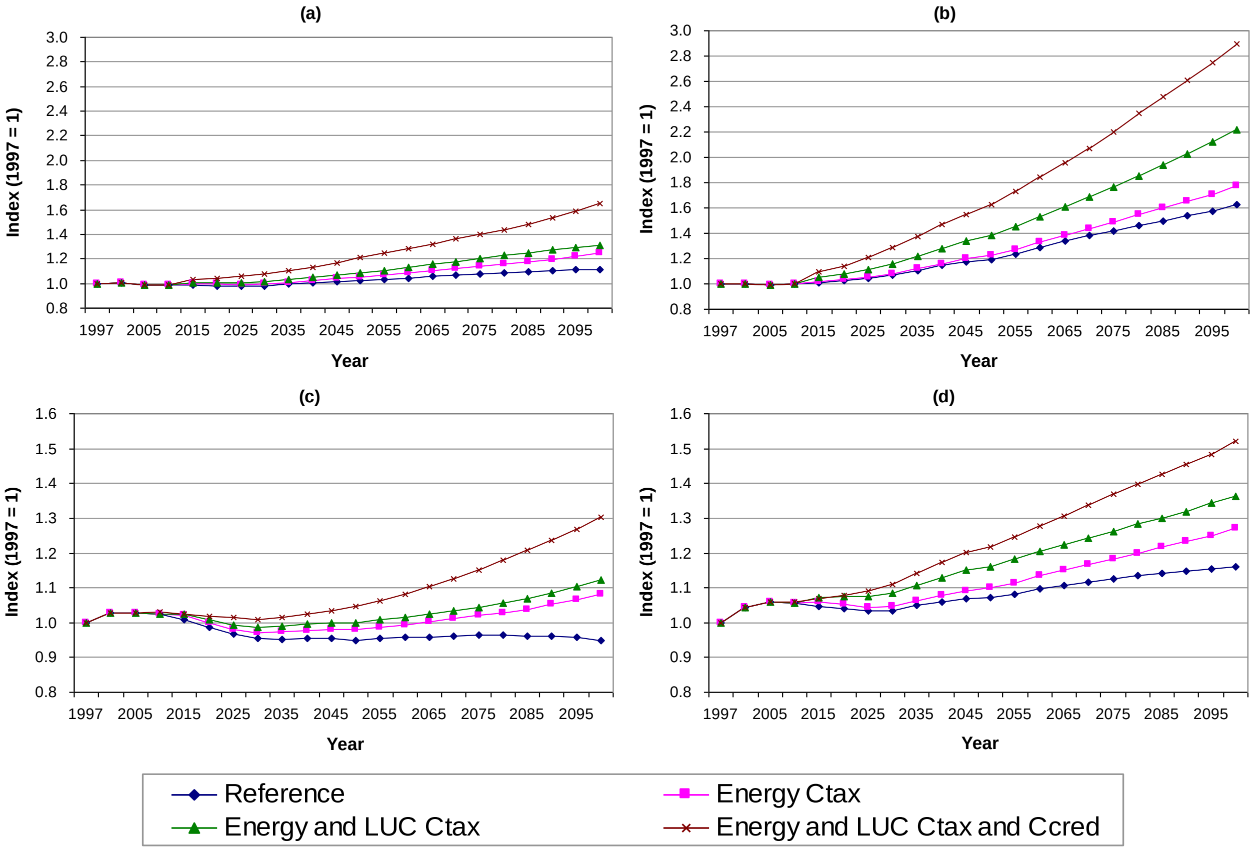

Figure 2. Livestock Price Indexes – high elasticities (a) and low elasticities (b); Crop Price Indexes – high elasticities (c) and low elasticities (d).

Table 5. World Cumulative Emissions, CO_2 Prices and Biofuels Production under alternative coalitions

	Reference	Global	Developed only	Developed +FSU	Developed +Asia*	Devoped +Lat.Am**	Developed +AFR	Developed +FSU +Asia*	Developed +FSU +Asia* +Lat.Am**
Cumulative Land Emissions 2015-∞ (Gt CO_2)	511	13	587	539	508	321	483	461	181
Cumulative Land Sequestration 2015-∞ (Gt CO_2)	220	670	371	476	372	390	405	475	490
Cumulative Net Land Emissions 2015-∞ (Gt CO_2)	291	-657	216	63	137	-70	78	-14	-309
Cumulative Fossil Emissions 2015-2100 (Gt CO_2-e)	7081	3220	3222	3201	3175	3265	3218	3153	3212
Leakage on Land Emissions (Gt CO2-e)			873	720	794	587	735	643	348
CO_2 Price 2015 ($/ton CO_2e)		10	10	10	10	10	10	10	10
CO_2 Price 2050 ($/ton CO_2e)		39	39	39	39	39	39	39	39
CO_2 Price 2100 ($/ton CO_2e)		280	280	280	280	280	280	280	280
Biofuels Output 2030 (EJ)		41	36	41	39	40	36	43	44
Biofuels Output 2050 (EJ)	27	73	111	111	111	88	105	110	87
Biofuels Output 2100 (EJ)	167	200	333	331	335	246	315	332	241

*CHN, IND and IDZ

** LAM and MEX