Greenhouse Gas Mitigation through Energy Crops in the United States with Implications for Asian-Pacific Countries

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Abstract

Agriculture-based biofuels have the potential to replace fossil fuels, thereby offsetting greenhouse gas emissions. We estimate emission abatement supply curves from energy crops switchgrass, hybrid poplar, and willow under a wide range of sector-wide greenhouse gas emission reduction incentives in U.S. agriculture. The Agricultural Sector Model employed captures market interactions of biofuel production with traditional agricultural production and with alternative emission mitigation strategies. U.S. results suggest an increasing importance of biomass-based electricity for carbon mitigation incentives above an economic threshold of $50 per ton. At incentive levels of $170 per ton and higher, emission offsets from energy crops provide the highest net emission reduction among all agricultural options. To extrapolate U.S. findings and assess the economic viability of energy crops in Asian Pacific countries, we conducted a sensitivity analysis on key parameters of the U.S. model. We find implementation of energy crops to be highly sensitive to biomass yields and agricultural land base. While U.S. crop yields can be matched in warm tropical climates, the available agricultural land base per capita is much smaller in most Asian-Pacific countries.

Key words: abatement supply curves, Agricultural Sector Model, biofuel offsets, energy crops, greenhouse gas emission mitigation, mathematical programming, poplar, sensitivity analysis, switchgrass, willow.

GREENHOUSE GAS MITIGATION THROUGH ENERGY CROPS IN THE UNITED STATES WITH IMPLICATIONS FOR ASIAN-PACIFIC COUNTRIES

Demand for agricultural participation in greenhouse gas (GHG) emission mitigation efforts has increased in recent years. While the original text of the Kyoto Protocol only considered carbon changes from deforestation, reforestation, and afforestation, subsequent efforts were made to determine agriculture's contribution in a broader spectrum (IPCC). Discussion now focuses on how rather than whether to involve agriculture.

Planting energy crops is one of many agricultural options under consideration. Crops such as switchgrass, short rotation woody trees, eucalyptus, and a variety of ethanol-generating plants can generate alternative biomass based energy and thus reduce the amount of fossil-fuel-based GHG-emission-intensive energy. While other agricultural options such as switching tillage systems or planting permanent trees saturate over time, GHG emission offsets from energy crops can be supplied continuously. Furthermore, emission offsets from energy crops are generally easier to implement than other agricultural emission abatement methods. For example, if a carbon market or a government institution prices one ton of carbon emissions at $50, all fossil fuel input going into energy crop production will most likely carry this price through increased purchasing cost, and all energy output will receive revenue based on the amount of fossil fuel energy offset. The net effect to the energy producer is the difference between increased revenue and increased cost.

Substantial research has been conducted in the United States and Canada on energy crops (Walsh et al.; Mann and Spath; Wang, Saricks, and Santini; Samson and Duxbury). These studies, however, did not account for trade-offs between the production of energy crops and other agricultural mitigation strategies. This analysis estimates the economic feasibility of energy crops in the United States in an environment where all major agricultural mitigation strategies are incorporated simultaneously.

Greenhouse gas emissions constitute a global problem that is not limited to the United States; it involves countries in the Asian-Pacific as well. In contrast to the United States and Canada, however, research on energy crops has been very limited in many Asian-Pacific countries. Here, the authors try to extrapolate results from the U.S. model to these countries. To reflect Asian-Pacific characteristics, a sensitivity analysis is conducted on key parameters of the U.S. model, which might differ between the United States and Asian-Pacific countries.

Background

Energy crops have been explored in the United States since 1978, almost 20 years before the Kyoto Protocol was established (U.S. DOE 2001). Major initial objectives involved reducing the dependency on foreign petroleum reserves and providing clean burning fuels. The potential to mitigate emissions of clean gases such as carbon dioxide was not emphasized until the 1990s when countries started to seriously negotiate greenhouse gas emission reduction programs.

Almost all energy crops produced in the United States today are still subsidized. Ethanol suppliers receive, on average, a $0.54 per gallon subsidy, which is even greater than the 1998-99 wholesale price of gasoline of $0.46 per gallon (Yacobucci and Womach). Governmental incentives to promote biomass power include project co-funding, various tax credits, deductions and exemptions, and direct subsidy payments (Badin and Kirschner).

Greenhouse gas emission mitigation efforts could improve the economics of energy crop production. If a market or governmental institution values carbon emission savings, energy crops would yield additional revenues equal to the carbon price times net emission savings relative to an energy equivalent amount of fossil fuel. The question then becomes, What carbon price level is needed to make energy crops economically feasible? In answering this question, one must analyze both energy crop possibilities and traditional agricultural production (Schneider) for two reasons:

1. Large-scale production of energy crops reduces the amount of land devoted to food production. As a consequence, aggregate food production is likely to fall,

causing food prices to rise and land values to increase. This effect may cause a negative feedback to energy crop production.

2. General mitigation incentives will promote a variety of agricultural strategies. McCarl and Schneider (1999, 2000) grouped agricultural GHG mitigation options into three broad categories: (*a*) reductions in agricultural-based emissions, for example, through diminished use of fossil fuels, fossil fuel intensive inputs, or livestock herd size reductions; (*b*) enlargements of agricultural based sinks, for example, through afforestation or tillage changes; and (*c*) increased production of commodities such as energy crops, which offsets emissions in other sectors of the economy.

Some agriculture mitigation strategies are mutually exclusive, some are complementary, and most interfere with traditional agricultural production. Hence, an independent analysis of a large-scale production of energy crops would most likely overestimate the economic potential.

U.S. Agricultural Sector Model

For this analysis we used a new version of the U.S. Agricultural Sector Model (ASM) (McCarl et al.). The ASM was first developed in the mid-1970s and has been used in many economic appraisals of environmental policies in the United States (see Chang et al. for references). Schneider modifies the ASM to include GHG emission accounting and mitigation possibilities. This new version is employed for this analysis and will hereafter be referred to as ASMGHG.

Scope of ASMGHG

The ASMGHG depicts production in 63 U.S. agricultural subregions, endogenizing crop choice, crop management, livestock numbers, and livestock management. Commodity coverage is broad: more than 30 commodities are considered, including the major U.S. feed and food grains, oilseeds, fiber, hay, silage, sweetener, cattle, sheep, poultry, dairy, and hog commodities. Production of eight major internationally traded commodities in 27 rest-of-the-world regions is included with detailed international trade depiction for those commodities. Trade and consumption of more than 50 other commodities are modeled at a more aggregate level. Production is gathered together into ten U.S. marketing regions and shipped on to processing, consumption, or international markets.

The ASMGHG solutions provide projections of land use and commodity production within the 63 U.S. areas, commodity production in the rest of the world, international trade, crop and livestock commodity prices, processed commodity prices, agricultural commodity consumption, producer income effects, consumer welfare effects, and various environmental impacts.

Greenhouse Gas Features in ASMGHG

The ASMGHG jointly incorporates all major GHG emission mitigation options available to agriculture for which reasonable data are available. For this study we considered only feasible potential strategies. Other strategies may become profitable in the near future as technology advances. However, we did not want to speculate as to when this might happen. Engineers are often overly optimistic about new technologies, not taking economics into account. Currently included strategies are listed below. For a detailed technical description of how these strategies are implemented in ASMGHG, see Schneider.

The ASMGHG mitigation strategies through the agricultural sector include

- afforestation;
- production of energy crops for use in electrical power plants;
- production of ethanol to replace fossil-fuel-based gasoline;
- soil carbon sequestration through tillage and crop choice and through conversion of arable land into permanent grassland;
- reduction in crop management emissions through alternative crop mix, fertilizer, irrigation, and tillage intensities;
- methane reductions through livestock herd size reduction, livestock, manure system improvements, enteric fermentation changes, and rice acreage reduction; and
- reduction in nitrous oxide emissions from livestock herd size reductions, and alternative fertilization, crop, and tillage choices.

Each individual emission and emission reduction category is individually accounted for but also aggregated into a measure of total carbon equivalents. To place different gases on an equal footing, methane and nitrous oxide are converted to carbon equivalents based on the Intergovernmental Panel on Climate Change (IPCC) 100-year global warming potentials (GWP): 21 for methane, 310 for nitrous oxide, and 44/12 for carbon.

The ASMGHG can examine the impact of various mitigation policies on the agricultural sector. At each incentive level, it identifies the optimal choice of mitigation strategy. In addition, impacts on the traditional agricultural sector are reported.

Economic Feasibility of Energy Crops in the United States

Competitive feasibility of major GHG emission mitigation strategies was simulated by running the ASMGHG under a wide range of carbon equivalent prices imposed on net emissions from agriculture. For emissions of non-carbon GHGs, prices were adjusted based on the GWP of the affected GHG relative to carbon. In addition, carbon credits from soil carbon sequestration and afforestation were value-discounted to reflect the saturating nature of these carbon sinks. McCarl and Murray provide a detailed description along with examination of many alternative setups. We chose an average setup leading to a 25 percent value discount for sequestered tree carbon and a 50 percent value discount for sequestered soil carbon (Schneider and McCarl). Thus, at a hypothetical carbon price of $20 per ton of carbon equivalent (TCE), land owners would receive $20 for each ton of offset carbon emissions, $10 for each ton of sequestered soil carbon, and $15 for each ton of carbon sequestered through afforestation and they would pay each ton emitted with $20 for carbon, $114.55 for methane, and $1,690.91 for nitrous oxide.

Major Impacts of Agricultural Greenhouse Gas Emission Mitigation Incentives

Figure 1 displays the resultant levels of emission abatement from agricultural mitigation strategies (see also Table 1). Unsubsidized energy crops as identified by current technologies are not competitive at zero carbon prices. Economic feasibility of biofuel crops begins at carbon prices above $50 per ton of carbon equivalent. Energy crops used as electrical power plant feedstock are more competitive than crops processed into gasoline substitutes such as ethanol.

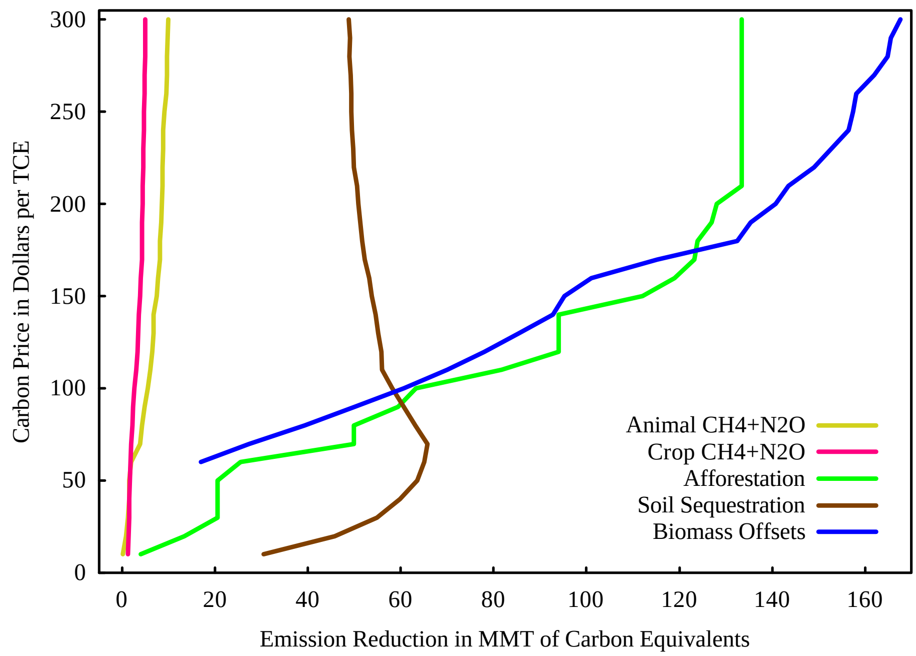

FIGURE 1. Role of major agricultural strategies to greenhouse gas mitigation at selected carbon equivalent prices

Under low carbon prices, agricultural management changes (e.g., tillage changes) are the preferred option. Above carbon incentives of $170 per ton of carbon equivalent, emission offsets from bioelectricity-generating crops dominate all agricultural mitigation strategies. At such high carbon prices the model favors mitigation options with the highest carbon saving potential per acre, outweighing higher operation and implementation costs of these strategies.

The results (Table 1) also show that large-scale bioelectricity production diverts farmland, reduces food supply, increases pressure to manage traditional agricultural products more intensively, increases food prices, and changes agricultural welfare distribution, with producers likely to gain and consumers likely to loose.

Economic versus Technical Potential

An important concept when regarding biofuel production involves the potential to mitigate GHG emissions. Physical scientists often quote very large estimates of potential, but these estimates typically neglect the cost of achieving that potential. We used ASMGHG under three settings to derive alternative measures of potential. The first represents technical

TABLE 1. Mitigation summary from the U.S. agricultural sector

Category	Unit	10	20	50	100	200	500
Major Ag-Mitigation Strategy							
Soil carbon sequestration	MMTCE	30,413	45,391	63,529	57,881	50,932	47,298
Afforestation	MMTCE	4,028	13,445	20,619	61,939	128,046	133,380
Bioelectricity	MMTCE	0	0	0	62,008	141,198	193,208
Subsidized corn-ethanol	MMTCE	2,893	2,893	2,893	2,893	2,893	2,893
Fossil fuel ag-inputs	MMTCE	1,540	2,941	5,771	7,118	9,315	11,567
Livestock technologies	MMTCE	184	908	1,622	5,547	8,570	14,304
Crop non-carbon GHG	MMTCE	1,314	1,461	1,750	2,721	4,426	5,782
Agricultural Production							
Irrigation	Percentage	18.95	17.89	16.57	19.84	22.03	26.55
Acreage	Mill Acres	333.4	332.2	329.3	298.4	248.4	215.7
Reduced tillage	Percentage	62.22	73.56	82.10	83.86	85.62	84.11
Nitrogen fertilizer	1,000 Tons	9,662	9,604	9,462	8,869	7,722	6,948
Farmers’ welfare	Billion $	0.42	0.93	2.59	9.62	18.47	60.70
Agricultural Market Effects							
Production	Fisher Index	99.80	99.33	97.91	91.08	77.85	67.47
Prices	Fisher Index	100.50	101.08	103.93	118.67	153.03	254.64
Ag-sector welfare	Billion $	-0.10	-0.32	-0.83	-5.72	-21.20	-40.62
Net exports	Fisher Index	99.33	97.85	94.12	73.52	35.51	23.41
Net Emission Reduction							
Carbon dioxide	MMTCO2	132	227	330	684	1188	1385
Methane	MMTCH4	0.04	0.14	0.25	1.22	2.22	3.32
Nitrous oxide	MMTN2O	0.02	0.02	0.02	0.04	0.07	0.1
Total carbon equivalents	MMTCE	37.5	64.2	93.3	197.2	342.5	405.5
Non-GHG Externalities from Crop Production (Excluding Trees andPerennial Energy Crops)							
Nitrogen	% Change	-0.9	-1.1	-0.7	-5.4	-26.6	-40.3
Phosphorous	% Change	-22.9	-36.1	-48.9	-52.2	-61.9	-66.2
Erosion	% Change	-13.2	-26.0	-40.0	-46.6	-58.4	-65.5

potential, the second, economic potential when only considering biofuels, and the third, competitive economic potential when considering all mitigation options.

The technical potential estimate was obtained by changing the ASMGHG's objective function from maximizing total economic surplus to maximizing bioelectricity-based emission offsets, thereby disregarding economics. This yields substantial emission offsets in the amount of 326 million metric tons carbon equivalent (MMTCE) annually (Figure 2). The single strategy economic potential takes into account all costs of bioelectricity generation except for the opportunity cost related to other possible agricultural mitigation strategies. Under such a setting, achieving only 50 percent of the technical potential requires carbon prices as high as $180 per TCE. Finally, all agricultural mitigation options were incorporated to find the competitive economic potential. This method yields the fewest emission offsets because implementation of other mitigation strategies limits the extent to which biofuel crops can be grown. The gap in the results between single strategy and competitive economic potential is reflective of inter-strategy competition and relative advantage. Some strategies are superior in some price ranges. It takes extremely high incentives to achieve anything close to the technical potential.

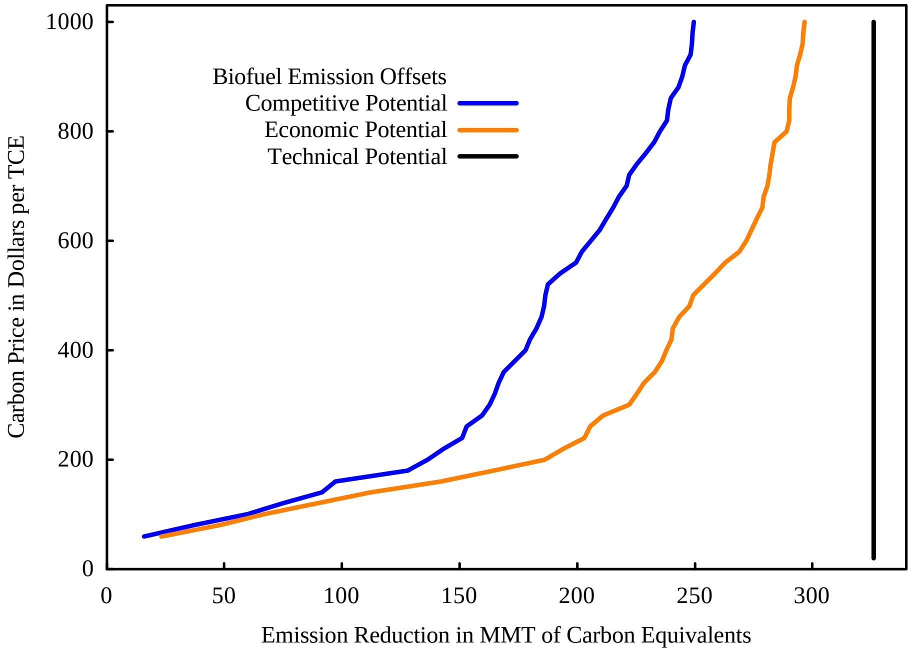

FIGURE 2. Comparison of various measures of carbon emission mitigation potential from energy crops

Sensitivity Analysis on Key Parameters of the U.S. Model

Agriculture in the United States is certainly very different from agriculture in Asian-Pacific countries. Differences exist with respect to soil, climate, culture-based preferences, per capita land availability, technology, and international market competition (FAO). To illustrate these differences, we conducted a sensitivity analysis on a few decisive model parameters of the U.S. agricultural sector model.

Biomass Yield

The competitiveness of energy crops depends on many technological parameters. We chose to examine alternative energy crop yields ranging from 50 to 200 percent of current U.S. yield estimates. Asian-Pacific biomass producers in moist tropical regions may benefit from generally higher plant productivity compared to the United States but could also experience lower productivity due to production conditions and altered input mixes. Duke, for example, reports U.S. comparable or higher biomass yields in Asian-Pacific countries for eucalyptus and panicum (Table 2).

TABLE 2. Energy crop yield comparison between the United States and Asian-Pacific countries

Species	Country	Yield Indicator MT/ha/yr	Reference
Eucalyptus	Australia	12-13 (ADM)	Duke
	India	33 (ADM)	Duke
	USA	**10–32.5 (ADM)**	Harwood
Leucaena leucocephala (Giant Ipil-Ipil)	**Philippines**	16-24 (NPP)	Durst
Hybrid Poplar	**USA**	**3.5-5.25 (ADM)**	Walsh et al.
Willow	**USA**	**3.15-5.77 (ADM)**	Walsh et al.
Panicum maximum (Guineagrass/ Hamilgrass)	Sri Lanka	4-7 (NPP)	Duke
	Taiwan	14-24 (NPP)	
	Thailand	20 (NPP)	
	India	1-40 (NPP)	
Panicum virgatum (Switchgrass)	**USA**	**3-7 (ADM)**	Walsh et al.
		9 (NPP)	Duke

Notes: ADM = Average Dry Mass, NPP = Net Primary Productivity.

Results show a strong impact of energy crop yields on supply of emission offsets (Figure 3). In most cases, increased yield leads to more than proportional increases in biomass emission offsets. For example, at a carbon price of $100 per TCE, energy crops offset about 58 MMTCE per year. A 50 percent yield increase leads to a 269 percent increase in emission offsets. In interpreting Figure 3, one should keep in mind that all yield increases were implemented without changing crop input parameters. If higher yields were based on higher input use, the effects would be less significant.

The results from yield scenarios are not limited to crop yield differences. They can be applied to all technological improvements, from farming to generation of bio-energy, that increase the emission-input/energy-output ratio.

Energy Price

There are two sources of revenues for producers of energy crops: (*a*) revenue from selling energy and (*b*) potential revenue from carbon emission offsets associated with

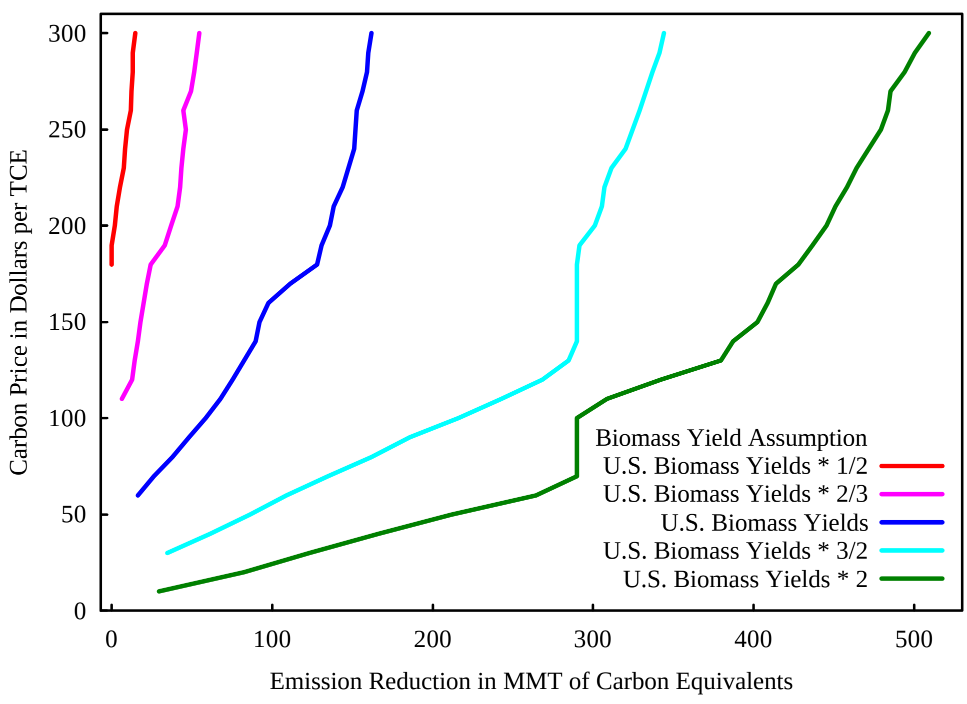

FIGURE 3. Changes in amount of emission offsets generated by energy crops when energy crop yields are altered

emissions-market-based income source. If the country is a major energy importer, then its electricity price is determined by the international energy market price.

Many Asian-Pacific countries, for example, Japan, South Korea, the Philippines, Taiwan, and Thailand, import substantial amounts of energy (Table 3). Because currency values differ between countries, the international market price may cause different incentives to grow biomass. For example, agricultural producers in energy-importing countries with a relatively low domestic currency value would earn a higher relative revenue from selling electricity than would U.S. biomass producers. Similarly, revenues would be low if conventional energy is cheap (energy-exporting countries or countries with high currency value). In this study we examine alternative prices for conventional electricity ranging from 50 to 200 percent of the current U.S. market price.

The effect of energy price changes on the amount of bioelectricity emission offsets is depicted in Figure 4. Note that a 100 percent energy price increase results in much less additional emission offsets than does a 100 percent yield increase. This occurs because selling electricity is only one profit source besides revenues from supplying carbon offsets. If, for example, selling electricity contributes 25 percent to total profits, then a 20 percent energy price increase results only in a 5 percent total profit gain.[1] As the carbon price increases, the electricity revenue becomes relatively less important, and energy price changes have less effect on the amount of emission offsets supplied. For example, a doubling of the energy price increases carbon offsets by 88 percent at $100 per TCE but only by 43 percent at $200 per TCE (Figure 4).

The results on energy price sensitivity are useful beyond extrapolation of U.S. results to foreign countries. They indicate how the energy crop's competitiveness changes as fossil fuel prices fluctuate in general. If the recent trend of increased fossil fuel prices continues, energy crop farming may soon be on the rise in the United States. Furthermore, the results also indicate how higher or lower costs of energy crop strategies would affect their competitiveness because higher energy prices are equivalent to lower production and processing costs.

Demand Elasticities

Energy crop production on agricultural land takes away land from traditional agricultural operations. As a consequence, traditional agricultural production, that is, food

TABLE 3. Energy indicators in selected Asian-Pacific countries based on U.S. Department of Energy

	Energy				
	Production	Consumption	Net Balance	Export	Import
Country	(Quadrillion BTU)			(% of Consumption)	
Australia	8.29	4.30	3.99	92.79	
Bangladesh	0.29	0.40	-0.11		27.50
Brunei	0.74	0.07	0.67	957.14	
China	33.13	33.93	-0.80		2.36
Hong Kong		0.67			
India	9.95	12.51	-2.56		20.46
Indonesia	7.49	3.62	3.87	106.91	
Japan	4.67	21.28	-16.61		78.05
North Korea	1.69	1.81	-0.12		6.63
South Korea	0.97	6.93	-5.96		86.00
Malaysia	3.21	1.74	1.47	84.48	
Mongolia	0.05				
New Zealand	0.65	0.79	-0.14		17.72
Pakistan	1.08	1.74	-0.66		37.93
Papua New Guinea	0.17	0.00	0.17		
Philippines	0.23	1.08	-0.85		78.70
Singapore	N/A	1.33			
Taiwan	0.49	3.31	-2.82		85.20
Thailand	1.15	2.34	-1.19		50.85
Vietnam	0.98	0.74	0.24	32.43	
Total Asian Pacific	75.41	99.27	-23.86		24.04
Russia	41.04	25.99	15.05	57.91	
USA	**72.81**	**94.79**	**-21.98**		**23.19**
World Total	382.18	377.72	4.46	1.18	

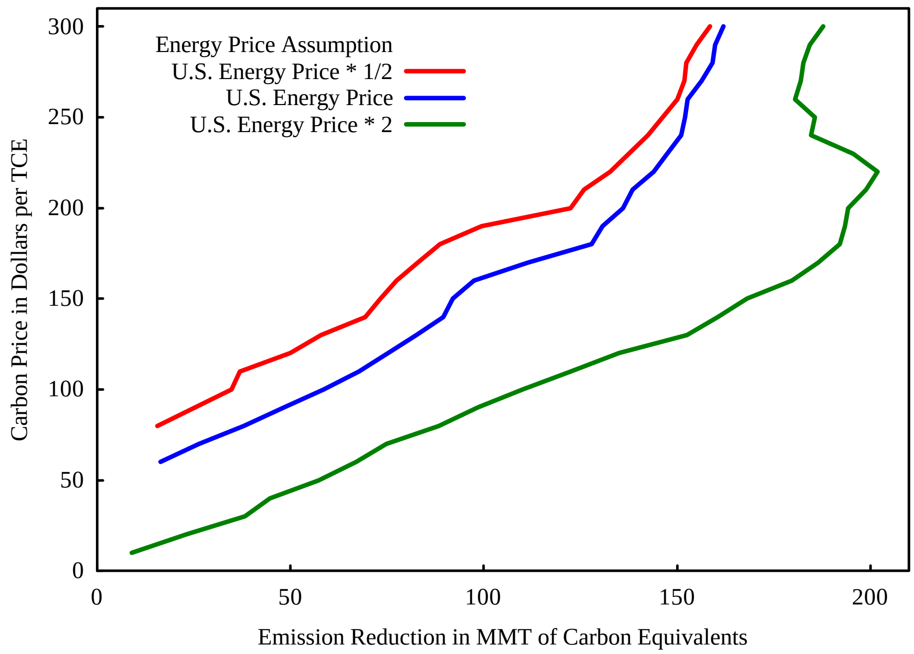

FIGURE 4. Changes in amount of emission offsets generated by energy crops when electricity prices are altered

production, will decrease, raising prices. The extent to which prices increase may depend on the elasticity of demand. ASMGHG explicitly defines demand curves for 48 primary agricultural products and more than 50 processed products. Demand curves are specified as constant elasticity functions. To assess the effect of higher or lower elasticities, we changed demand elasticities across all primary agricultural products to (*a*) 50 percent and (*b*) 200 percent of the original value.

Modifications of demand elasticity assumptions did not significantly affect the amount of emission offsets supplied from energy crops. Figure 5 shows that different domestic demand elasticities have almost no effect on supply of bioelectricity. Similar results were obtained when altering export and import elasticities for traded agricultural commodities. Note that elasticities were equally modified across all commodities. In reality, elasticities in foreign countries may be higher or lower depending on the commodity in question.

Land Availability

The United States has a large agricultural land base relative to its population (Table 4). Therefore, taking food cropland away for the production of energy crops may be cheaper in the United States but more expensive in densely populated countries, which heavily depend

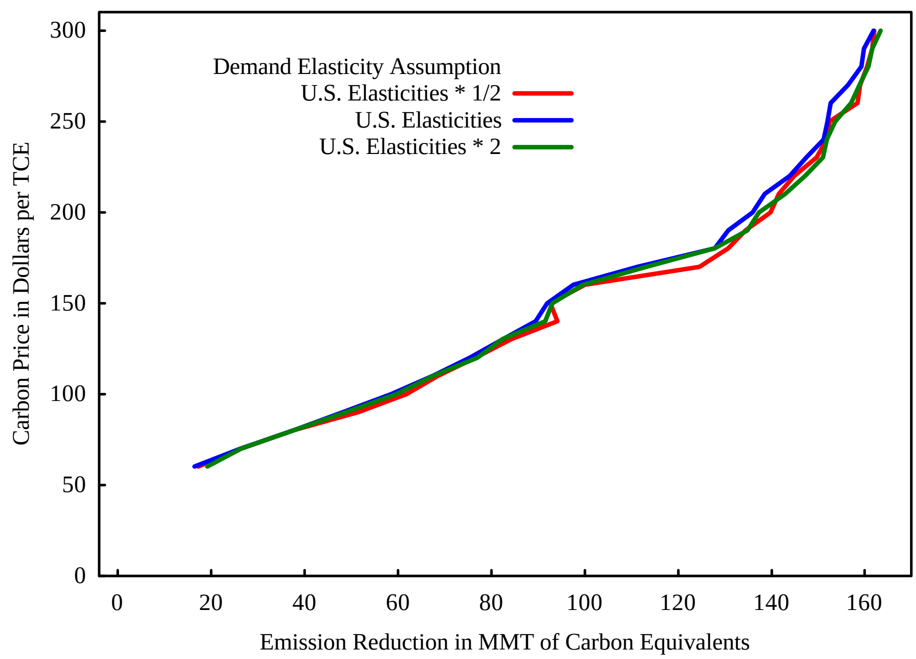

FIGURE 5. Changes in amount of emission offsets generated by energy crops when domestic agricultural demand elasticities are altered

on domestic food production. To illustrate such differences we modified the available agricultural land base in the United States to between 50 to 200 percent of its original value.

Figure 6 shows the supply of bioelectricity emission offsets for different assumptions about the amount of available agricultural land. Not surprisingly, we find energy crops to be very sensitive to land availability. If the U.S. agricultural land base were cut in half, energy crops would not become profitable below carbon prices of $260 per TCE (Figure 6). These results indicate the importance of opportunity costs of farmland for the economic feasibility of energy crops. Less land implies less production, higher commodity prices, and thus higher revenues in the traditional agricultural sector. Consequently, farmers have to give up more by growing energy crops. Limited availability of agricultural land may be a major obstacle to growing energy crops in the Asian-Pacific area.

TABLE 4. Populations and land availability in selected Asian-Pacific countries based on the Food and Agriculture Organization information

Country	Population (1,000)	Area (1,000 hectares)			Area per Person Relative to U.S.		
		Total	Ag-Land	Arable	Total	Ag-Land	Arable
Australia	18,701	774,122	472,000	53,775	12.21	16.67	4.49
Bangladesh	126,947	14,400	8,932	7,992	0.03	0.05	0.10
Bhutan	2,064	4,700	460	140	0.67	0.15	0.11
Cambodia	10,945	18,104	5,307	3,700	0.49	0.32	0.53
China	1,274,107	959,805	535,566	124,144	0.22	0.28	0.15
Fiji Islands	806	1,827	460	200	0.67	0.38	0.39
India	998,056	328,759	180,600	161,500	0.10	0.12	0.25
Indonesia	209,255	190,457	42,164	17,941	0.27	0.13	0.13
Japan	126,505	37,780	5,405	4,535	0.09	0.03	0.06
North Korea	23,702	12,054	2,050	1,700	0.15	0.06	0.11
South Korea	46,480	9,926	1,969	1,708	0.06	0.03	0.06
Laos	5,297	23,680	1,678	800	1.32	0.21	0.24
Malaysia	21,830	32,975	7,890	1,820	0.45	0.24	0.13
Mongolia	2,621	156,650	118,469	1,321	17.63	29.85	0.79
New Zealand	3,828	27,053	16,580	1,555	2.08	2.86	0.63
Pakistan	152,331	79,610	27,040	21,425	0.15	0.12	0.22
Papua New Guinea	4,702	46,284	760	60	2.90	0.11	0.02
Philippines	74,454	30,000	11,280	5,500	0.12	0.10	0.12
Russian Federation	147,196	1,707,540	217,155	126,000	3.42	0.97	1.34
Singapore	3,522	62	1	1	0.01	0.00	0.00
Sri Lanka	18,639	6,561	2,329	869	0.10	0.08	0.07
Thailand	60,856	51,312	21,175	16,800	0.25	0.23	0.43
Vietnam	78,705	33,169	7,892	5,700	0.12	0.07	0.11
USA	**276,218**	**936,352**	**418,250**	**176,950**	**1.00**	**1.00**	**1.00**

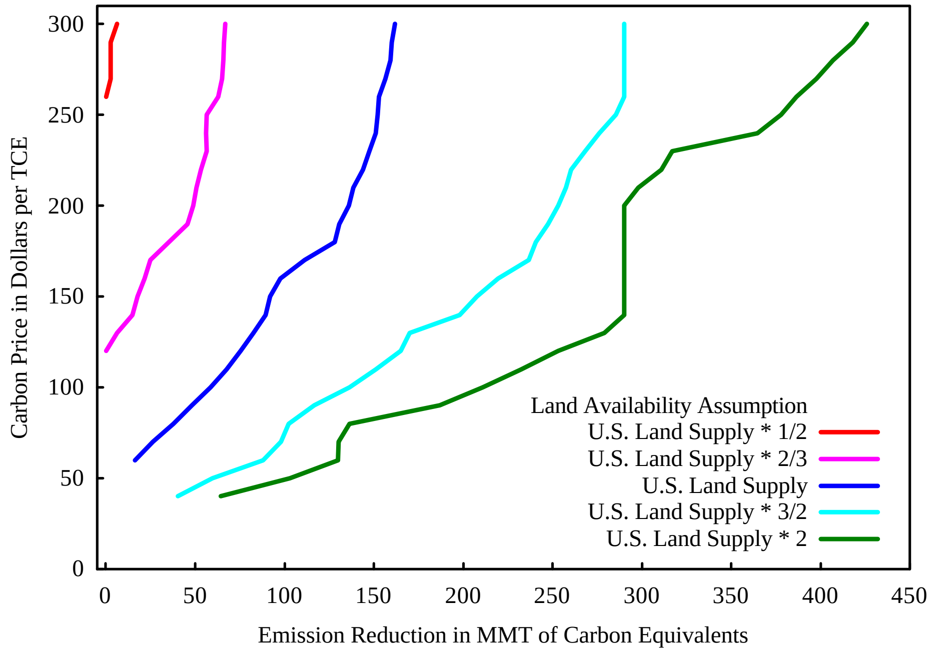

FIGURE 6. Changes in amount of emission offsets generated by energy crops when land availability is altered

Conclusions

Energy crops supply fossil fuel alternatives and therefore have the potential to reduce greenhouse gas emissions. Economic feasibility implies that the energy output has to be greater than the energy input; otherwise—in the absence of subsidies—growers could not yield a profit. The attractiveness of energy crops relative to fossil fuels depends on the net emission balance and the value of carbon offsets. In addition, growing energy crops must be economically superior to other possible land use strategies.

Assessments of energy crops in the U.S. agricultural sector show that biomass-based electricity (based on switchgrass or short rotation woody crops), while expensive, has considerable potential to offset carbon emissions. Emission offsets range between 1 and 2 metric tons per acre per year. However, a financial support of at least $60 per ton of carbon equivalent (about $30 per dry ton) is needed to make them economically feasible. Paying less than $60 per ton of carbon offset induces other agricultural mitigation options, for example, changes in tillage, fertilization, and irrigation. Ethanol-generating energy crops turned out to be an inferior strategy over the whole range of carbon prices.

We also tried to generalize U.S. results through a sensitivity analysis on key parameters and to infer for Asian-Pacific countries. Results indicate that implementation of energy crops in the United States is highly sensitive to yields, land availability, and the price of energy but relatively insensitive to demand elasticities of traditional agricultural commodities. With the exception of Australia and Russia, most of the Asian-Pacific countries have far less arable land per capita than has the United States (FAO). Allocation of currently cultivated land to energy crops in those countries would imply less land available to produce food. Shortages in domestic food supply, however, could only be offset through increased food imports. Thus, energy crops in most Asian-Pacific countries may not be economically feasible unless food imports are cheaper than energy imports.

Endnote

1. Suppose p = e + c, where p represents total profit, e represents energy revenue, and c represents carbon offset revenue and that the ratio of carbon revenue to energy revenue is known, i.e., c/e = r. Substitution yields the following identity: p = e + er = (1 + r)e. If the energy revenue is increased by a factor f, the new profit (np) can be calculated as np = te + c = te + er = (t + r)e. Thus, np/p = (t + r)/(1 + r). Setting r = 3, a 20 percent energy revenue increase (t = 2) implies a total profit increase of 5 percent.

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