An Analysis on Potential Economic Impacts of Greenhouse Gas Mitigation through Planting Energy Crops in Taiwan

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Abstract

The purpose of this study is to evaluate the economic and environmental impacts of planting energy crop on set-aside acreages in Taiwan. To do so, a Taiwan Agricultural Sector Model (TASM) was built and the data parameters of energy crop were incorporated into this model in order to simulate the economic and environmental impacts. Simulation results show that GHGE mitigation depends on the planting acreage of energy crops in which the optimal planting acreage of energy is determined by the profit of other agricultural products as well as government subsidy on energy crop. Therefore, the mitigation of GHGE depends on the government subsidy on energy crop per hectare. Such subsidy is also suitable for the green box by the regulation of WTO.

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I. Introduction

Biomass has attracted lots of discussions on the future energy supply in the U.S. and European since 1970. In the U.S., biomass currently provides about 4% of the energy produced and it is predicted to supply 20% of the energy in the near future. Keuzen (1992) in the report of Netherlands Scientific Council for Government Policy summarized that 40 to 100 million hectares in the European Unit (EU) may become available for purposes other than food crop production during the next decades (Hanegraaf et. al., 1998). Wood, crops, and animal wastes are all included in the biomass where energy crops are the major biomass to play an important role in the future energy supply.

Due to the limitation of technology on producing energy (electricity or ethanol) and the consideration of production cost of energy crops, the current possible extension energy crops are Switchgrass and Short Rotation Wood Crops (hybrid poplar and hybrid willow). Promoting energy crops may have significantly impacts on agricultural sectors, environments, farmers' revenue, and government budget. As an example of a higher agricultural production cost country like Taiwan, the currently set-aside cropland acreage is increasing to 200,000 hectares which is about 1/3 of total cropland areas. As Taiwan joined World Trade Organization (WTO), agricultural commodity markets are opened and result in decreasing planting acreage. For instance, planting acreage in rice was 400,000 hectares in 1992 and it is decreased to 306,000 hectares in 2002 and such trend is predicted continuum. Meanwhile, rural economics including farmers' revenue in Taiwan have been hard pressed since domestic agricultural markets open. Therefore, Government in Taiwan proposes a

Set-Aside Program which subsidize NT$90,000 per hectare a year to those who particpitate this program in order to maintain farmer' revenue. However, such program does not have much contribution on environment or land conversion.

On other hand, government in Taiwan also spends her budget on purchasing rice and such expenditure has to be cut following the regulation of WTO on Aggregate Measurement of Support (AMS). Although the subsidy on Set-Aside program is listed in Blue Box, it may have the potential to be limited. How to transfer government expenditures from Amber or Blue Box to a Green Box in order to maintain farmers' revenue in Taiwan is an important issue on policy adjustment. Planting energy crops is another option for such policy adjustment since it has significantly contribution on environmental issues, such as mitigation on green house gas emission, soil erosion, ground water depletion, and biodiversity.

Taiwan does not produce any oil or coal except imports. Expenditures on importing foreign coal in 2002 was 665 $US million. Three electric utilities are now importing low-sulfur coal and producing 55,267 million kwh electricity with 48.8 million ton Carbon Dioxide emission. Due to the consideration of trade balance on oil or coal, promoting energy crops in Taiwan is needed to evaluate.

The purpose of this study is to evaluate the economic and environmental impacts of planting energy crop on set-aside acreages in Taiwan. To do so, a Taiwan Agricultural Sector Model (TASM) was built and the data parameters of energy crop were incorporated into this model in order to simulate the economic and environmental impacts. Simulation results show that GHGE mitigation depends on the planting acreage of energy crops in which the optimal planting acreage of energy is determined by the profit of other agricultural products as well as government subsidy on energy crop. Therefore, the mitigation of GHGE depends on the government subsidy on energy crop per hectare. Such subsidy is also suitable for the green box by the regulation of WTO.

II. Background of Energy Crops

Literatures (Walsh 1998, Michigan Biomass Energy Program 2002) have shown that the possible promotion energy crops are Herbaceous crops such as Switchgrass and Short Rotation Woody Crops such as Poplar and Willow because of higher yield with lower production cost and wide geographical distribution, and the technology possibility of co-firing with coal. So these three energy crops are the representative energy crops here.

The report in the Energy Crops and Their Potential Development in Michigan shows that there are many advantages of planting Switchgrass including less demand in irrigation and fertilizer, preventing soil erosion, pest and resistant, and higher yield with lower production cost. Switchgrass is estimated about 5.4 d tons per acre per year with US$ 1347 revenue while the production cost is around US$ 947 per acre as shown in Appendix I. For the Polar and Willow, the estimated yield are 41.5 and 15.6 d tons per acre respectively. The total revenue of Polar and Willow are US$ 1043 and US$2091 per acre while the production costs are US$ 924 and US$2171 per acre.

The major contribution of planting energy crops is on the mitigation of green house gas emission while co-firing with coal to produce electricity. Following Hanegraff et al, and Schneider and McCarl estimation, the mitigation of GHGE is estimated about 10-15% on Carbon Dioxide using 90% coal with 10% energy crops co-firing.

The other environment impacts of planting energy crops include energy balance, emission of acidifying gases, soil erosion, ground water depletion, and contribution to biodiversity following the summaries in Hanegraff et al. For instance, Abrahamnson et al. proved that Short Rotation Wood Crops provide good foraging and breeding habit for a diversity of birds. The found that 57 different species regularly used SRWC while 28 species were found to breed in SRWC plots. On other hand, Maskiner found that after incorporating Willow biomass crops into riparian buffers, it could produce clean water with renewable energy.

III. ASMGHGE Model

In this study a price-endogenous spatial equilibrium model is used to evaluate the potential economic impacts including GHGE mitigation, production, consumption, land use, and welfare distribution through planting energy crops in Taiwan agricultural sector. This section describes the structure of Taiwan Agricultural Sector Model(TASM). The TASM is formulated in a multi-product partial equilibrium framework based on the previous work of Baumes (1978), Burton (1987), McCarl and Spreen (1980), Chang et al. (1992), Coble et al. (1992) and Tanyeri-Abur et al (1993). The empirical structure has been adapted to Taiwan and used in a number of policy-related studies, e.g., Chang and Chen (1995) and Chang (1999). The current version of TASM accommodates more than 90 commodities for 4 major production regions which can be further divided into 15 sub-regions.

Base TASM

Under the perfect competitive and price-taking assumptions, price-dependent product demand and input supply curves are used to replicate market operations. First, we assume that there exists I agricultural commodities which are produced in K regions through production activities $X_{ik}(i=1,2,...,I ; k=1,2,...,K)$. The unit of each activity X_{ik} is a hectare. The total production in each region can be calculated by multiplying per hectare yield Y_{ik} with X_{ik}. For product demand, we assume all commodities are sold in the wholesale markets. The prices faced by consumers can be represented by the national average of wholesale prices. Assume demand functions are integrable and can be represented by the following inverse demand functions:

$$P_i^Q = \psi(Q_i) \qquad i = 1,2,...,I$$

where Q_i is the total quantity of consumption and P_i^Q is the average wholesale price of commodity *i*.

In the input markets we assume each production activity must apply regional inputs (such as land and labor) and *N* inputs purchased from the non-farm sector (such as fertilizer and chemicals). The prices of *N* purchased inputs are exogenous. However, the prices of regional inputs are endogenously determined by the derived demand from the production activities and regional supply functions. Assume regional supply functions for cropland and other resource are integrable as follows:

$$P_k^L = \alpha_k(L_k) \qquad k = 1,2,...,\mathrm{K}$$

$$P_k^R = \beta_k(R_k) \qquad k = 1,2,...,K$$

where P_k^L, P_k^R are cropland rent and the user prices of other resource and L_k, R_k are the cropland and other resource quantity supplied respectively.

The objective function which maximizes the sum of consumers' surplus plus producers' surpluses is used to simulate a perfectly competitive market equilibrium following Samuelson (1952), Takayama and Judge (1964). It is defined as the area between the product demand and factor supply curves to the left of their intersection as follows:

$$Max: \sum_i \int \psi(Q_i)dQ_i - \sum_i \sum_k C_{ik} X_{ik} - \sum_k \int \alpha_k(L_k)dL_k - \sum_k \int \beta_k(R_k)dR_k$$

The constraints are:

$$Q_i - \sum_k Y_{ik} X_{ik} \quad \leq \quad 0 \qquad \qquad \forall\, i$$

$$\sum_i X_{ik} - L_k \quad \leq \quad 0 \qquad \qquad \forall\, k$$

$$\sum_i f_{ik} X_{ik} - R_k \quad \leq \quad 0 \qquad \qquad \forall\, k$$

where C_{ik} is the purchased input cost in region k used in producing the i^{th} commodity, Y_{ik} is per hectare yield of i^{th} commodity produced in region *k*, and f_{ik} is the demand for the regional input in region k. Terms Q_i and X_{ik} are endogenous variables while C_{ik}, Y_{ik}, and f_{ik} are known parameters.

Modeling Domestic Policy (Farm Program)

The following two sets of domestic policy variables are also added into the model. The first set is used to reflect the government rice purchase program under a guaranteed price which is above the market equilibrium price. An import ban is used to assure farmers a reasonable return. A high guaranteed price and tight restriction on rice imports stimulate excess production resulting in a rapid accumulation of surplus rice, a shortage of elevator space, and an escalating government deficit. Per hectare limits on rice purchases have been implemented since 1977. Letting P_i^G be the weighted government guaranteed purchases price and Q_i^G the total amount of government purchase. The total amount from the government rice purchase program ($P_i^G * Q_i^G$) is added into the objective function as additional revenues for the farmers.

The second set of policy variables relates to the Set-Aside Program in Taiwan. After trade liberalization, Taiwan imports more agricultural commodities from world market following with decreasing in the domestic production. To maintain farmer’s income and cropland in agricultural sector, “Set-Aside” program is implemented in Taiwan. Farmers could receive a subsidy payment (P^L) as they participate this "Set-Aside" program. The set-aside hectares in 2002 is about 200,000 ha where the subsidy payment is about NT$90,000 per ha in Taiwan.

Modeling Trading Policy

Taiwan's import/export share in the world market is very small. Therefore, import and export prices are assumed to be determined exogenously by supply and demand in the world market. In other words, Taiwan is a price-taker in the international agricultural product markets. Taiwan is importing a lot of agricultural products from the world. However, such import are accompany with three different trading policies. The first one is an import tariff while the second one is quota and the last one is TRQ. For instance, grains and most of fruits are imported with a lower import tariff while rice is imported with quota system. The livestock products are imported with TRQ.

Modeling Energy Crops

Three energy crops is incorporated into the TASM by adding production activity into the model. Energy crop budget data with its prices are needed in order to let model work. Energy crop budget data with prices are form Ugarte et. al. and Schneider and McCarl which is listed in Appendix I.

To reflect above policy and energy crop production activity, the objective function and constraints of TASM have been modified as follow:

$$Max: \sum_i \int \psi(Q_i)dQ_i - \sum_i \sum_k C_{ik} X_{ik} - \sum_k \int \alpha_k (L_k) dL_k - \sum_k \int \beta_k (R_k) dR_k + \sum_i P_i^G * Q_i^G + \sum_k P^L * AL_k$$

$$+ \sum_i \sum_i \int ED(Q_i^M) dQ_i^M + \sum_i \int EXED(TRQ_i) dTRQ_i - \sum_i \int ES(Q_i^X) dQ_i^X - \sum_i [tax_i * Q_i^M + outtax_i * TRQ_i]$$

Subject to:

$$Q_i + Q_i^X + Q_i^G - \sum_k Y_{ik} X_{ik} - (Q_i^M + TRQ_i) \le 0 \qquad \forall\, i \qquad (2)$$

$$\sum_i X_{ik} + AL_k + \sum_j EC_{jk} - L_k \le 0 \qquad \forall\, k \qquad (3)$$

$$\sum_i f_{ik} X_{ik} - R_k \quad \leq \quad 0 \qquad \forall\, k \tag{4}$$

where

Q_i^G	Government purchasing quantity in product i
Q_i^M	Import quantity of product i
TRQ_i	Import quantity exceeding the quota
Q_i^X	Export quantity of product i
$ED(Q_i^M)$	Inverse excess demand curve of product i
$ES(Q_i^X)$	Inverse excess supply curve of product i
$EXED(TRQ_i)$	Inverse excess demand curve of product i that the import quantity is exceeding quota.
tax_i	Import tariff for product i
$outtax_i$	Out-of-Quota tariff for product i
AL_k	Set-Aside acreage in region k
EC_{jk}	Planting acreage of energy crop j in region k

Equation (1) is the objective function after incorporating domestic and trade policies. The first term of the first line in the objective function is the area under demand curve while the second and third terms are total production cost and the last term is government subsidy on purchasing commodity and set-aside payment. Therefore, the first line could represent the social welfare in a closed market. The first and second terms of the second line in the objective function are the area under the excess demand curve while the third term is the area of excess supply curve. The last term of second line represents the tariff revenue. Therefore, the second line in the objective function could represent the trade surplus.

Equation (2) is the balance constraint for commodity. The first three terms in equation (2) is called total demand which includes domestic demand (Q_i), export demand (Q_i^X), and government purchasing (Q_i^G). The last second terms in the supply-demand balance constraint represents the supply side where it includes domestic production $(\sum_k Y_{ik} X_{ik})$ and import $(Q_i^M + TRQ_i)$. Finally, equations (3) and (4) are the resource endowment constraints. Equation (3) shows that agricultural crops, energy crops, and set-aside acreage are competing for the cropland and the equilibrium condition indicates the marginal benefit on planting agricultural products, or energy crops will be equal set-aside payment.

The TASM includes 60 crops, 5 floral crops, 7 livestock, 3 types of forests (conifers, hardwoods, and bamboo) and 17 secondary commodities (including 2 timber products: conifer-timber and hardwood-timber). The total value of the primary commodities accounts for 85 percent of Taiwan's total value of agricultural product. Sub-regional production activities are specified in the model for each commodity. Crop, livestock and forestry mixes activities and constraints are also specified at the sub-regional level, but the input markets for cropland, pasture land, forest land, and farm labor are specified at the regional level.

The data sources largely come from published government statistics and research reports, which include the Taiwan Agricultural Yearbook, Production Cost and Income of Farm Products Statistics, Commodity Price Statistics Monthly, Taiwan Agricultural Prices and Costs Monthly, Taiwan Area Agricultural Products Wholesale Market Yearbook, Trade Statistics of the Inspectorate-General of Customs, Forestry Statistics of Taiwan. Demand elasticities of agricultural products come from various sources.

The empirical model is validated based on the comparison between the equilibrium solution and actual statistics. The year 2002 was chosen as the baseline to construct the database, and we use both the total production and prices as the basis to validate our model. Table 1 shows that most of the discrepancies between model results and year 2002 data are within 6% range and thus the model should be valid for our simulation.

IV. Simulation Results and Policy Implications

The yield on electricity by using coal is around 2,442 kwh/ton with 884 ton/kwh CO2 emission. Three power plants utilize coal to produce 55,267 million kwh electricity in Taiwan, therefore, causes 48.8 million ton of CO2 emission that is about 28.7% of total CO2 emission in Taiwan. If energy crops is co-fired with coal to produce electricity, then the CO2 emission could be mitigate given same amount of electricity output. Following Olsen and Plunkett et al. studies, we fount that the most current technology in producing electricity using coal with co-firing with energy crops is 10% co-firing. Therefore, the following simulation is based on 10% co-firing technology.

Bain and Amos estimated that the ratios of energy crops with coal are different. The ratio of Switchgrass is about 58.38% and 67% for Poplar while 63.25% for Willow. If the energy crops replace 10% of coal quantity to produce electricity, then production quantity for Switchgrass, Poplar, and Willow are 3.87, 3.37, and 3.58 million metric ton respectively as shown in Table 3. Therefore, the planting acreages with these three energy crops are 292, 33, and 92 thousand hectares. If the coal usage is cut by 10%, then the CO2 emission mitigation will be 4.8 million metric ton which is about 2.82% of the total CO2 emission.

One of the purposes of this study is to evaluate the possibility of planting energy crops using the current Set-Aside acreages. In Table 4, the current subsidy by Set-Aside program is 2,342 $US/ha/yr while the profit of plating energy crops are ranged from 8.99 to 117.6 $US/ha/yr which is smaller than the Set-Aside payment. Farmers in Taiwan will not plant energy crops due to the less economic incentive. The optimal subsidy for planting energy crops is calculated in the third and fourth columns in Table 4. The optimal subsidy for Switchgrass, Poplar, and Willow are 2222.4, 2312.6, and 2333 $US/ha respectively and could be transferred as the carbon subsidy 134.6, 1567, and 148.5 $US/carbon ton. Such carbon subsidy is close to the carbon tax estimated in Li et al. (2003).

The comparison results from Tables 3 and 4 indicate that planting energy crops is possible but limit by Set-Aside acreages. To simulate the economic and GHGE impacts by planting energy crops, the budget data and prices of energy crops are incorporated into the above TASM. Energy crop budget data and prices are from Ugarte et. al, and Schneider and McCarl which is shown in Appendix I. The simulation results are shown in Table 5. Switchgrass will be the most productive energy crops which produce 1.59 million tons using 119.7 thousand hectares. If Switchgrass is co-fired with coal, then it could mitigate about 1.99 million CO2 emission, reduce the 27 $US million expenditure on importing coal and also save Government payment on Set-Aside which is 280.33 $US million.

Assuming 10% co-firing technology, the CO2 emission mitigation from these three energy crops is 2.66 million ton which occupies 1.56% of total CO2 emission in Taiwan. Such results show that agricultural sector may have potential contribution on GHGE mitigation for industry in Taiwan. On other hand, central government could reduce the expenditure by 51.1 $US million where the payment on energy crops is 368.01 $US million while the expenditure reduction on buying coal and Set-Aside payment are 36.22 and 382.91 $US million.

V. Conclusion

The purpose of this study is to evaluate the economic and environmental impacts of planting energy crop on set-aside acreages in Taiwan. To do so, a Taiwan Agricultural Sector Model (TASM) was built and the data parameters of energy crop were incorporated into this model in order to simulate the economic and environmental impacts. Simulation results show that with the assumption of 10% co-firing technology, the CO2 emission mitigation from these three energy crops is 2.66 million ton which occupies 1.56% of total CO2 emission in Taiwan. Such results show that agricultural sector may have potential contribution on GHGE mitigation for industry in Taiwan. On other hand, central government could reduce the expenditure by 51.1 $US million where the payment on energy crops is 368.01 $US million while the expenditure reduction on buying coal and Set-Aside payment are 36.22 and 382.91 $US million. GHGE mitigation depends on the planting acreage of energy crops in which the optimal planting acreage of energy is determined by the profit of other agricultural products as well as government subsidy on energy crop. Therefore, the mitigation of GHGE depends on the government subsidy on energy crop per hectare. Such subsidy is also suitable for the green box by the regulation of WTO.

Table 1. Model Validation

	Observed Data	Model Solution	Deviation
Rice Price(NT$/kg)	23.51	25.80	9.74
Production Quantity(ton)	1,061,793	1,069,508	0.72
Government Purchasing Quantity(ton)	323,956	329,533	1.72
Rice Planting Acreage (1000 hectares)	306.84	307.84	0.32
Set-Aside Acreage(1000 hectares)	184.00	178.20	-3.15
Government Payment on Set-Aside Program(NT$ Million)	7,051	7252	3.55
Government Payment On Purchasing Program (NT$ Million)	8,500	8,534	0.40

Table 2. The Basic Energy Data in Year 2002 in Taiwan

Items with per unit	
Electricity per ton of coal (kwh)	2442
CO_2 emission (ton/kwh)	884
SOx emission (ton/kwh)	0.569
NOx emission (ton/kwh)	0.678
Items with total amount	
Coal Import Volume(ton)	22,631,896
Total Electricity (million kwh)	55,267
Total CO_2 emission (ton)	48,856,108
Total SOx emission (ton)	31,447
Total NOx emission (ton)	37,471

Table 3. The Impacts of GHGE Reduction of Energy Crops with 10% Co-Firing with Coal

	Switchgrass	Poplar	Willow
Energy Crop production (ton)	3,876,652	3,377,895	3,578,165
Yield (d ton/ha/yr)	13.2	10.2	11.5
Planting Acreage (ha)	292,005	329,477	30,9798
Coal quantity reduction(ton)	2,263,190	2,263,190	2,263,190
Coal Expenditure saving (US $Million)	66.5	66.5	66.5
CO2 Mitigation (ton)	4,885,610	4,885,610	4,885,610
SOx Mitigation (ton)	3,144	3,144	3,145
NOx Mitigation (ton)	3,747	3,747-5,620	3,747-5,620
CO2 Sink (ton)	5,548,095	329,480	928,670

*for Switchgrass is 58.38%, 67% for Poplar, and 63.25% for Willow.

*CO2 sink is the number of planting acreage times the number of CO2 sink in Appendix II.

Table 4. The Comparisons of GHGE by Energy Crops and Total Carbon Emission in Taiwan

$US/ha/year

Energy Crops	Set-Aside Subsidy*	Profit** (A)	Subsidy**		Total Profit (A+B)
			Subsidy by hectare(B)	Carbon Subsidy ($US/ton)	
Switchgrass	2,342	117.6	2224.4	134.6	2,342
Poplar	2,342	29.36	2312.64	156.7	2,342
Willow	2,342	8.99	2333.01	148.5	2,342

*Set-Aside Subsidy is the government payment to those who participate Set-Aside Program.

**Profit item is from the Returns in Appendix I after converting acre to hectare.

***Carbon Subsidy is the endogenous number that farmers will plant energy crops if their total profit is higher than the Set-Aside Subsidy.

Table 5. The Economic and GHGE Impacts by Planting Energy Crops

	Production (tons)	Planting Acreage (1000 ha)	CO2 Emission Reduction (Million tons)	Gov. Payment ($US Million)	Coal Expenditure Reduction ($US Million)	Set-Aside Payment Reduction ($US Million)
Switchgrass	1,589,427	119.7	1.99	266.21	27.09	280.33
Poplar	194,864	19.0	0.28	43.94	3.83	44.50
Willow	286,263	24.8	0.39	57.86	5.30	58.08
Total	2,070,554	163.5	2.66	368.01	36.22	382.91

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Appendix I. Energy Crop Production Budget Data Per Year

	Switchgrass	Poplar	Willow
Mature Yield（d ton/acre）	5.37	4.15	4.68
Prices ($/d ton)	40.00	42.32	43.87
Revenue（$）	153.43	104.34	95.06
Seed Cost（$）	2.16	12.34	31.90
Fertilizer N（$）	26.24	2.13	6.41
Fertilizer P（$）	0.45	0.71	0.00
Fertilizer K（$）	0.63	0.50	0.00
Fertilizer Lime（$）	3.25	1.03	0.00
Chemical（$）	1.46	3.43	4.01
Labor（$）	1.66	1.52	0.33
Mach Var（$）	2.57	2.03	0.37
Mach Fixed（$）	3.70	2.70	0.54
Interest OPI（$）	1.62	15.33	10.69
Harvest Cost（$）	58.59	43.66	42.88
Chemical（$）	2.84	2.62	0.57
Labor（$）	0.10	0.39	0.10
Mach Var（$）	0.20	1.49	0.33
Mach Fixed（$）	0.30	2.58	0.57
Total Cost（$）	105.79	92.45	98.70
Returns（$）	47.64	11.89	3.64

Appendix II. Green House Gas Emission Mitigation and Sink by Energy Crops

Unit: %, ton /hectare/year

	Switchgrass			Poplar or Willow		
Carbon Emission Reduction	CO2	NOx	SOx	CO2	NOx	SOx
Olsen	7%	31%	0			
Energy Crops and Their Potential Development in Michigan				10%	10%	10%
Schneider and McCarl				5%	5%	5%
Ney et al.	29%	29%	29%			
	10%	10%	10%			
Carbon Sink						
Jorgensen and Jorgensen	10-19					
Ralph and Sims				8-10		

Olsen found that the emission reduction on CO2 and NOx are 7% and 31% using 10% Switchgrass co-firing with coal.