The development of input-monitoring system on biofuel economics and social welfare analysis

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Abstract
Biofuel production relies on stable supply of biomass which would be significantly influenced by climate-induced impacts. Since the actual agricultural outputs are relatively unpredictable in the face of uncertain environmental conditions and can only be realized in the harvest season, providing useful information regarding the stability of biomass supply to the downstream biofuel industry is crucial. This study firstly illustrates a theoretical framework to explore the resultant market equilibrium and optimal conditions of agricultural and bioenergy production in the face of highly uncertain environmental risks and then employs a two-stage stochastic programming model to investigate the optimal biofuel development and associated economic and environmental effects. The results show that total welfare may not always increase because the loss of other agricultural commodities induced by climate impacts may be greater than the gains received by biofuel production and emission reduction. This study provides insights into the area where artificial intelligence monitoring system can be implemented to analyze the input data associated with agricultural activities and help the biofuel industry to improve its production possibilities.

Keywords
Bioenergy, climate change, stochastic programming, uncertainty, welfare

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Introduction

The extensive use of fossil fuels has resulted in climate change that has induced many phenomena such as desertification, sea-level rise, increased possibility of extreme events, and sudden shifts in land use.\textsuperscript{1-3} Since fossil fuel is non-renewable that would inevitably be depleted and the use of this resource would result in environmental unsustainability, biofuel that reduces the reliance on fossils and mitigates climate change has been greatly developed and promoted in recent years.

While biofuel is considered an effective approach, the supply of energy crops depends on cropping decisions and thus the farming patterns will have substantial influences on the effective and efficient development of biofuel.\textsuperscript{4,5} Additionally, Since water resource (i.e. irrigation) is probably an important production input in many industries and climate change has caused the changes in regional temperature and precipitation, competition for the uncertain water resource among sectors will inevitably affect the water availability in the agricultural sector,\textsuperscript{6,7} and consequently, alter the use of other production inputs, cropping patterns, and biofuel development.

This study examines the biofuel production in Taiwan which imports more than 99% of energy and has promulgated a strict environmental regulation that forbids the increase in the use of fossil use in 2015.\textsuperscript{8} Therefore, the energy shortage can only come from renewable energy sources\textsuperscript{9} and some advanced artificial intelligence applications that immediate point out the stability of biomass supply might be used to improve the production strategy.\textsuperscript{10,11} Taiwan is a small island situated between 21.7° and 25.5° northern latitude with approximately a total area of 36,000 km\textsuperscript{2}. The total cultivated land before 2005 was about 0.83 million hectares (ha) or 23% of the territory. Since a substantial amount of cropland is released after the intensified competition of international agricultural markets, utilization of the idle land to promote biofuel production is of particular interest to the administrative authority of Taiwan.

This study aims to investigate how Taiwan’s biofuel production is affected in the face of climate-induced impacts and to what extend the the monitoring system may benefit. This study theoretically investigates the potential competition of agricultural resources among consumers and suppliers and simulates the market equilibrium of cropping and biofuel production patterns. A stochastic programming with recourse model that integrates the water, agricultural, and environmental sectors to assess the net biofuel production is proposed. Various energy and emission prices are also examined to unfold the economic and environmental benefits of biofuel development.

With the completion of the objectives, this study makes several contributions. First, this study explores the new equilibrium of agricultural activities under uncertain climate impacts. With this knowledge, the government would be able to formulate a more effective policy to assist the development of biofuel. Second, the full production cycle regarding resource use, sectoral activities, and environmental risks are theoretically demonstrated and empirically validated. This framework is more comprehensive and would benefit future agricultural, bioenergy, and environmental studies.

A sustainable and reliable energy supply is a crucial driving force to improve economic growth and technological innovation. In the past, to ensure the development of society, the fossil fuel that emits a substantial amount of CO\textsubscript{2} is intensively involved
in many industries, but numerous environmental problems have also been evidenced by its use. According to the reports of the Intergovernmental Panel on Climate Change, the anthropogenic emissions of greenhouse gases is warming the earth by approximately 0.5 °C and at the end of 21st century, the global temperature may further increase to 1.4 °C to 5.8 °C. Such a rapid shift in temperature would inevitably result in numerous adverse consequences ranging from increased desertification, sudden land shift, loss of ice cap, a rise in ocean level, and possible increased occurrences of hurricanes, all of which play important roles in sustainable social development. Therefore, it is necessary to explore cleaner and sustainable energy sources to alleviate such environmental problems and sustain social development.

Bioenergy is considered an attractive possibility because it reduces total emissions during the energy production and consumption cycle. Conventionally bioenergy, especially biofuel, is produced by the energy crops such as corn, sweet sorghum, sugarcane, soybean, and oilseeds, but such applications would result in a substantial reduction in the export of commodities and volatilize the food markets. To alleviate the fluctuation in food prices, bioenergy technology is continually evolving. Results point out that it is too early to give up biofuel because the second-generation biofuels (i.e. cellulosic technology) can utilize the crop residuals into biofuel production, which reduces the requirement of energy crops and stabilizes food prices. A further examination also shows that the production cost would be greatly reduced with the innovation of such conversion technologies. Unders such circumstances, it is necessary to improve the production efficiency of biofuel industry by optimizing the resource allocation.

Additionally, there is merit to point out that biofuel production may result in a large-scale shift in cropland due to alterations of agricultural activities. Since agricultural products have lower process than other products and irrigation is generally guaranteed to secure food production, the price for irrigation water, along with other agricultural inputs, is usually set up at a lower level. Based on the economic point of view, such an allocation of water resources is not efficient because the water allocations for activities yielding the greatest social benefits may not be satisfied.

Since the scale of Taiwan’s agricultural and biofuel production is relatively small, studies indicate that machine learning may be applied to use such a small dataset to improve decision-making process and if the user interface can be designed appropriately, we may be able to delineate the more efficient biofuel production strategy in Taiwan. The water resource is generally limited because of the rapid growth of the world population, and thus competition in water resources becomes more severe among water-intensive sectors such as municipal, industry, and agriculture.

Nevertheless, climate change has resulted in numerous environmental events including changes in temperature and precipitation, all of which are likely to alter the regional water distribution and allocation. Therefore, the regional supply of water resources should not be treated as constant as before because climate change has imposed uncertainty on water availability. Under such circumstances, more detailed investigations concerning efficient water allocation are needed. The impacts of climate change on agriculture have long been investigated using different scales. For example, researchers apply the erosion productivity impact calculator (EPIC) model to study how agricultural production responds to climate change. Additionally, a study extends this concept by...
incorporating economic and environmental components in a reduced-form model. They showed that farmers would choose to mix crops and cultivars in the face of global warming. However, some studies\(^{35}\) show that the farm-level production should be further analyzed because the net agronomic benefits are directly influenced by the sectoral agricultural activities and the overall agro-economic effects can be determined only when the whole agricultural sector is incorporated. Under such a circumstance, a number of studies\(^{14,35-40}\) point out that the farming decisions and consumers’ responses must be incorporated into a sectoral or national framework to determine useful market equilibrium.

As aforementioned, biofuel is an attractive approach to deal with climate change and can stabilize energy supply, improve energy security, and enhance environmental sustainability.\(^{41,42}\) Thus it is obvious that effective biofuel production depends on constant feedstock collection and processing, implying that the sudden shock on or changes in farming patterns of energy crops are likely to result in substantial impacts on the renewable energy supply.\(^{43,44}\) For this reason, to explore the efficient development path and effects of biofuel production, it is necessary to aggregate climate-induced impacts on water allocation and subsequent agricultural activities into the analysis. Thus, a stochastic framework that accommodates environmental risks should be proposed rather than using deterministic analysis that treats the endogenous risks at a constant level.

**Methods**

Since the model structure involves agricultural activity, energy supply, environmental management, and resource allocation, we first illustrate how they are theoretically interrelated and then propose the mathematical equilibrium model to explore analytical solutions.

**Residual and competitive resource use**

Figure 1 depicts the behavior and market equilibrium of water users. In general, in a region where the water resource is abundant, all the users choose to utilize water till the marginal benefit from water use decreases to zero. Under such a circumstance, the value of water is equal to zero and water users consider only the marginal benefits received from water-related activities. This behavioral pattern actually can be applied to general resource allocation concept and thus, in Figure 2 we would discuss a more general concept regarding resource utilization in the face of market operations.

The situation of resource utilization and allocation becomes much more complex when resources are used in a competitive way. As shown in Figure 2, when the users compete for limited resources (i.e. resource price is no longer zero), they choose to use the resource until the marginal benefit from using that resource is equal to its price.

The optimal quantity of resource use is generally determined at point \(E_0\) with price \(P_0\), given the original resource demand curve \((D_0)\) and supply curve \((S_0)\). However, the demand and supply of resources could vary under climate change due to changes in production decision and strategy. Consider a situation in which precipitation decreases and temperature increases where the water supply could fall, thereby shifting the water supply
curve up to $S_1$. Assuming that the climate condition has a trivial effect on water demand, the new equilibrium moves to $E_1$. Because water supply decreases and the water demand remains constant, water users bid up the water price to $P^1$, resulting in water use of $Q^1$. Alternatively, if the water supply curve shifts to $S_2$, the water price decreases and water demand increases. In addition, if a user perceives that production would require more water because of higher temperatures, the water demand curve would shift outward to $D_1$, resulting in a new equilibrium of water resource at $E_2$. 

Figure 1. Residual water use.

Figure 2. Resource use under competition.
Policy impacts on supply and demand

The demand and supply curves would alter in the face of supportive agricultural policies such as the commodity repurchase program. Figure 3 shows the changes in demand (D) and supply (S) curves of crops in the face of the repurchase program. Because the government repurchase price $P_i^G$ must be greater than the market equilibrium price $P_e$, it kinks the demand curve from $DD'$ to $DD''$. Otherwise, the market consumes all commodities up to the original equilibrium $E$. In the face of a higher market price, the quantity supply increases from original equilibrium $E$ to the new equilibrium $E'$. Therefore, the total welfare will change from area DES to area DFE'S, with an increment of $FE'E$. Because area $DFE'S$ can be expressed as the sum of $DFGO + FE'HG - SE'HO$, area $FE'HG$ represents the producers’ expense on energy crop. This change depicted as $\sum P_i^G*Q_i^G$ in the 5th term, is then added to the objective function. The 6th term expressed as $\sum k * P_k^L * A_k$ reflects the government expenditure on Taiwan’s aside cropland.

Implementation of input-monitoring system

Figures 1 to 3 indicates how biomass supply of biofuel producers may be affected by farming decisions. To effectively produce biofuel and improve production possibilities, it is necessary to enhance the ability of predicting the stability of the input supply. Since the crop yield can only be observed at the harvest season, which is too late for biofuel producer to shift their production strategy, an input-monitoring system recording immediate uses of agricultural inputs can provide useful information to biofuel producers who can subsequently adjust their production strategies would improve the overall production efficiency of renewable development.

Theoretical model formulation

The theoretical foundation of sectoral analysis has been well developed and widely applied by numerous studies including acid rain, environmental assessment.
ethanol production, climate impacts, carbon sequestration, and policy evaluation.

Since bioenergy production depends on agricultural outputs, availability of production resources, and climate condition, it is necessary to integrate these components into a single model to provide a complete analytical framework. The integrated social welfare ($ISW$) calculated the optimatal production and resource allocation is defined in Equation (1).

$$\begin{align*}
ISW = & \sum_i \int \omega(\text{CONQi})d\text{CONQi} - \sum_{ip} \int \alpha_{ip}(\text{IRRLAND}_{ip})d\text{IRRLAND}_{ip} \\
& - \sum_{ip} \int \beta_{ip}(\text{DRYLAND}_{ip})d\text{DRYLAND}_{ip} - \sum_{ip} \int \gamma_{ip}(\text{LABOR}_{ip})d\text{LABOR}_{ip} \\
& - \sum_{ip} \sum \sum \sum \text{PROCOST}_{inp}\text{PRODUCTION}_{inp} \\
& - \sum_{m} \sum \sum \sum \text{PUMPCOST}_{pz}\text{AGWATER}_{pcm} - \sum_{i} \int \text{EXCESSD}(Q^M_i)dQ^M_i \\
& + \sum_{i} \int \text{EXED}(TRQi)dTRQi \\
& - \sum_{i} \int \text{EXESSS}(Q^X_i)dQ^X_i + \sum_{i} (\text{taxi} \ast Q^M_i + \text{outtaxi} \ast TRQi) + \sum_{i} \text{REF}^G_i \text{REQ}^G_i \\
& + \sum_{p} \text{LANDSUB}^L\text{SUBLAND}_p + \\
& \sum_{j} \text{ENGSUB} \text{ENGLAND}_j - \text{EMIP}_{GHG} \sum_{g} \text{EMIF}_{gip}\text{EMISSION}_{gips} \\
& + \sum_{p} \sum \sum \text{irrcost}_{z}\text{LANDTYPE}_{pz} - \sum_{p} \sum \sum \text{landcost}_{pk}\text{CROP MIX}_{pk} \quad (1)
\end{align*}$$

Equation (1) is the objective function that maximizes social welfare by maximizing efficiency of resources used among agricultural production strategies and sectors. Domestic agricultural and bioenergy subsidies, international trade policies, and carbon emission trade markets are also specified so that the most valuable production pattern in each state of nature can be delineated. With this formulation, bioenergy production and emission reduction are activated and codetermine the optimal agricultural production. This objective function is subject to the following constraints:

$$\begin{align*}
\text{CONQi} + Q^X_i + \text{REQ}^G_i & \leq \sum_p (\text{DRYYIELD}_{ip}\text{DRYPROD}_{ip} + \text{IRRYIELD}_{ip}\text{IRRPROD}_{ip}) \\
(Q^M_i + TRQi) & \quad \forall i \\
\end{align*}$$

Equation (2) adds the production strategies facing changes in resource availability to link farmers’ planting decisions to the resource endowment.
\[
\sum_i \mu_{ip} IRRPROD_{ip} + \sum_i \rho_{ip} DRYPROD_{ip} \leq LABORAVAIL_p \quad \forall p \tag{4}
\]

\[
\sum_in \sigma_{ip} IRRPROD_{ip} + \sum_in \rho_{ip} DRYPROD_{inp} \leq INPUTSAVAIL_{np} \quad \forall p \tag{5}
\]

Similarly, Equation (3) constrains total land usage by separating agricultural activities based on irrigation strategies. Equations (4) and (5) are additional resource constraints for production activities. They indicate that the use of labor and \( n \) production inputs must be less than the sum of their endowments and purchases in all regions.

\[
\sum_{i,p} EMIF_{gip} EMISSION_{gips} + MUNEMI_g + INDEMI_g \leq NETEMI_g \quad \forall g \tag{6}
\]

Equation (6) is a constraint indicating that emissions from the agricultural, municipal, and industrial sectors must be less than their total emissions. This constraint thus allows bioenergy production to improve environmental quality (i.e. reduce emissions).

**Theoretical analysis**

Given the nature of price endogeneity, the optimal framework allows resources to be allocated for their most efficient use, and the optimal condition of each resource involved can be illustrated by using Lagrangian and Kuhn–Tucker conditions. The first-order conditions that maximize these variables can be derived using Kuhn–Tucker conditions, which are presented and discussed in the following subsections.

\[
\frac{\partial L}{\partial IRRPROD_{ip}} = -\left( \sum_i \sum_p IRRPROCOST_{ip} \right) + \gamma_1 (1 + YIELDCHANGE_i) \sum_p IRRYIELD_{ip} \tag{7}
\]

\[
\frac{\partial L}{\partial IRRPROD_{ip}}(IRRPROD_{ip}) = 0 \tag{8}
\]

\[
\frac{\partial L}{\partial DRYPROD_{ip}} = -\left( \sum_i \sum_p DRYPROCOST_{ip} \right) + \gamma_1 \sum_p DRYYIELD_{ip} \tag{9}
\]

\[
\frac{\partial L}{\partial DRYPROD_{ip}}(DRYPROD_{ip}) = 0 \tag{10}
\]

Equation (7) is the condition for the optimal production of irrigation land. It is determined by its production cost (IRRPROCOST) and the marginal value of production, which is determined by the shadow price \( \gamma_1 \), crop yield change, and per hectare production. Equation (8) is the complementary condition to ensure that as long as production is positive, the marginal cost must equal the marginal benefit. Equations (9) to (10) represent the
same conditions for dryland land production.

\[
\frac{\partial L}{\partial CONQ_i} = \omega(CONQ_{ir}) - \gamma_1 \tag{11}
\]

\[
\frac{\partial L}{\partial CONQ_i}(CONQ_i) = 0 \tag{12}
\]

Equations (11) and (12) are conditions for optimal commodity consumption. Equation (11) shows that consumers consume products up to the marginal value of the product (the shadow price, in this case). Equation (12) is the complementary condition.

\[
\frac{\partial L}{\partial IRRLAND_{ip}} = -\alpha_{ip}(IRRLAND_{ip}) - \gamma_2 \tag{13}
\]

\[
\frac{\partial L}{\partial IRRLAND_{ip}}(IRRLAND_{ip}) = 0 \tag{14}
\]

\[
\frac{\partial L}{\partial DRYLAND_{ip}} = -\beta_{ip}(DRYLAND_{ip}) - \gamma_2 \tag{15}
\]

\[
\frac{\partial L}{\partial DRYLAND_{ip}}(DRYLAND_{ip}) = 0 \tag{16}
\]

Equation (13) is the condition for optimal use of irrigation land. This condition shows that irrigation land is employed until the marginal cost of using this land equals the marginal value of the product from this activity. Equation (14) is the complementary condition of irrigation land use. It ensures that the optimal use of irrigation land is satisfied only when the marginal cost of using the land equals the marginal benefit from this land. Equations (15) and (16) represent the same conditions for dryland land usage.

\[
\frac{\partial L}{\partial AGWATER_{pm}} = -PUMPCOST_{pz} - \gamma_3 = \delta_{ip}IRRPROD_{ip} - \gamma_3 = 0 \tag{17}
\]

Equation (17) is the condition for optimal use of irrigation water. This condition shows that water is used optimally only if the marginal cost of using water equals the marginal value from such use; otherwise, the allocation is not efficient. Since the water use among sectors faces the same marginal cost (\(\gamma_3\)), implying that water should be freely transferred to the sector that yields the highest marginal value to achieve the social optimum.

\[
\frac{\partial L}{\partial EMISSION_{gip}} = EMIP_{GHG} - \gamma_6 \tag{18}
\]

\[
\frac{\partial L}{\partial EMISSION_{gip}}(EMISSION_{gip}) = 0 \tag{19}
\]

Equation (18) shows that the optimal level of emissions should be set equal to its shadow price; otherwise net social welfare is not achieved. In other words, beyond the point \(\gamma_6\), the benefit from emitting an additional unit of emissions is not able to offset its production.
cost Equation (19) is the complementary condition of Equation (24).

\[
\frac{\partial L}{\partial \gamma_1} \gamma_1 = \left( CONQ_i + Q_i^X + REQ_i^G - (Q_i^M + TRQ_i) - \sum_p (DRYIELD_{ip} DRYP_1D_{ip} + IRRYIELD_{ip} IRRP_1D_{ip}) \right) \gamma_1 = 0
\]

Equation (20) shows the complementary slackness condition, which represents that either the commodity price is zero if production activity is not employed or that the commodity price is positive if production activity is fully engaged.

\[
\frac{\partial L}{\partial \gamma_2} \gamma_2 = \left( \sum_i IRRLAND_{ip} + \sum_i DRYLAND_{ip} + SUBLAND_p - LANDTYPE_p \right) \gamma_2 = 0
\]

Equation (21) is the complementary slackness condition to land price. It shows that if the land is used, the land price is nonzero to reflect the scarcity of this resource; otherwise, the land price is zero.

\[
\frac{\partial L}{\partial \gamma_3} \gamma_3 = \left( \sum_i \delta_{ip} IRRP_1D_{ip} \leq \text{WATERAVAIL}_p \right) \gamma_3 = 0
\]

Equation (22) is the complementary slackness condition to water price. It shows that if water is used, the water price is nonzero to reflect its scarcity; otherwise, the land price is zero (i.e. there is more resource than needed and it is not bounded).

\[
\frac{\partial L}{\partial \gamma_4} \gamma_4 = \left( \sum_{i,p} EMIF_{gip} EMISSION_{gips} - NETEMI_g \right) \gamma_6 = 0
\]

Equation (23) is the complementary slackness condition to emission price. It shows that emissions are produced at a cost to reflect the negative impact on the environment. In the cases where emission is considered environmentally friendly, then the cost of producing emissions would be zero.

**Results**

**Biofuel production**

This study uses 2010–2018 Taiwan Agricultural Data to validate the usefulness of the model, and the results are displayed in Table 1. Since the commodity productions of major commodities only slightly deviate from the observation and the simulated market prices are close to the market prices, we claim that the proposed model could be useful in biofuel and policy analysis.

Figure 4 shows that biofuel production is positively related to the gasoline price. At the historical high gasoline price (e.g. NTS$40 per liter), total biofuel production would reach 481 million liters, and more than 300 million liters even if the gasoline price is lower than
Table 1. Model validation.

| Products       | Production (ton) | Price (NT$/kg) |
|----------------|------------------|----------------|
|                | Observation      | Deviation      | Observation | Deviation |
| Rice           | 1,333,018        | 0.32%          | 28.61       | 3.46%     |
| Corn           | 167,908          | 1.94%          | 5.56        | -0.18%    |
| Peanut         | 58,066           | -19.56%        | 36.41       | -7.16%    |
| Hog            | 864,792          | -0.19%         | 86.91       | -1.13%    |
| Broiler Chicken| 304,354          | 3.87%          | 58.17       | 1.47%     |
| Native Chicken | 266,161          | 1.36%          | 89.56       | 0.64%     |
| Egg            | 7,018,647        | -0.28%         | 1.61        | 0.01%     |

Figure 4. Biofuel production under various gasoline prices.

NT$30 per liter. Based on the results, we find that biofuel production is less influenced by slight climate-induced impacts on rainfall distribution and yield changes.

We also investigate crop production and emission reduction under various gasoline prices. Because the higher energy price would result in a higher gain in energy sales, production of energy crops would be increased. Depending on the level of gasoline price, the emission reduction would range from 35,000 tons to 55,000 tons. However, since the total resource is limited, it is necessary to investigate how biofuel promotion would alter the cropping pattern of other commodities. The results are presented in Table 2. (Figure 5)

Resource allocation

Figure 6 shows that when crop yield is altered under climate impacts, regional cropping patterns would be significantly, regardless of gasoline prices. The results imply that for
farmers to maximize their income, they would incorporate the climate-induced yield change into farming decisions. Consequently, the fertilizer use would change substantially. In addition, the fluctuation of fertilizer use in central Taiwan also indicates that bioenergy production is likely to result in considerable effects on farming decisions.

Figure 6 investigates how irrigation alters in the face of climate impacts. The results show that in most production regions the cropping decision is likely to switch when the availability of surface water becomes uncertain. Along with the existence of profitable energy crop plantations, irrigation used for commodity crops will decline in most areas. The results indicate that energy crops that consume less water should be firstly

| Gasoline Price | NT$18 | NT$20 | NT$22 | NT$24 | NT$26 | NT$28 |
|----------------|-------|-------|-------|-------|-------|-------|
| Production of Energy Crops | 2,729 | 2,937 | 3,003 | 3,143 | 3,351 | 3,455 |
| Emission Reduction | 34,944 | 37,856 | 38,768 | 40,768 | 43,680 | 45,136 |
| Gasoline Price | NT$30 | NT$32 | NT$34 | NT$36 | NT$38 | NT$40 |
| Production of Energy Crops | 3,557 | 3,669 | 3,806 | 3,887 | 4,012 | 4,119 |
| Emission Reduction | 46,592 | 48,166 | 50,086 | 51,251 | 52,998 | 54,497 |

**Figure 5.** Potential changes in fertilizer use.

**Table 2.** Results of crop production and emission offsets.
cultivated in the north, east, and south of Taiwan to ensure that the food commodities have access to uncertain surface water.

Figure 7 displays the production and uses of sweet potatoes under different supportive prices. In the face of high gasoline prices, more land will be used to plant sweet potatoes because its demand has increased sharply while keeping the supply of edible parts constant.

The promotion of biofuel production is an effective approach to alleviate energy insecurity and global warming, but its net effect may not be desirable when climate-induced impacts are taken into account. Figure 8 shows that the total social welfare declines when crop yield and water supply become uncertain. Under such a circumstance, the more the biofuel is produced, the higher the welfare loss could be expected. This is because conventional commodities must compete for limited and uncertain water with profitable energy crops, and thus the gains in biofuel production could be offset by the loss of other crops.

Discussion

Market operations

The production of bioenergy is substantially influenced by the market conditions such as changes in gasoline prices and electricity prices. Since Taiwan is a price-taker and has no
control and impact on the fuel markets, price fluctuation on these prices would inevitably result in considerable effects on Taiwan’s bioenergy development. For this reason, an effective hedging strategy should be considered to stabilize the investment cost so that the profits of biofuel producers can be guaranteed. In addition, the bioenergy industry should collaborate with conventional energy providers to prevent the sudden shock in fossil fuels to alleviate the potential hurts on bioenergy production and have in-depth innovation on the conjunctive application of both fossil and biofuel energy sources.

Figure 7. Alternative uses of energy crops.

Figure 8. Welfare change under market operations.
With this effort, it is likely to greatly improve the efficiency and effectiveness of bioenergy production in the face of unsystematic risks.

Establishment of the emission trade system

Another issue related to biofuel production is whether the gains from emission offset can be effectively received by the producers. Because the value attached by the emission offset is generally countable and transferrable, it is important to design a market to allow the realization of the gains. Currently, there is no such a market in Taiwan, and thus the establishment of the emission trade system would be an determinant factor influencing total biofuel production; otherwise, the incentives to biofuel producers would be greatly declined.

Uncertain climate impacts

Many studies generally use past patterns to investigate the effectiveness of biofuel production. However, climate-induced impacts such as changes in temperature, rainfall, and crop yields that directly alter farming decisions and agricultural activities should be taken into account. Since such impacts generally differ from region to region, a detailed assessment and forecasting of local climate patterns should be conducted to unfold the agricultural impacts and subsequent bioenergy development; otherwise, a great deviation of the bioenergy production could result and the development would not achieve the optima.

Technology innovation and promotion

This study investigates biofuel production, emission reduction, and resource allocation under alternative energy prices and climate patterns. However, biopower that generates electricity may also be applied. Under such a circumstance, the feedstock supply, technology switch, and technology selection would make the analysis even complicated. Additionally, the second-generation biofuel technology that consumes cellulosic materials as primary feedstock also emerges, thereby providing another branch in biofuel production. Therefore, the competition among bioenergy possibilities should be considered because the use of feedstocks and the final forms of bioenergy would be different.

Development of on-time monitoring system

In order for biofuel producers to effectively utilize their production capitals under climate impacts and uncertain biomass supply, the development of on-time monitoring system is a key because under such impacts the supply of biomass is not constant that potentially affects the production efficiency of biofuel. Thus if the on-time monitoring system can be developed to convert the input use data that is quickly available by the biofuel companies, the producers would be able to know the possible changes in future biomass supply and then adjust their production technologies and strategies accordingly.
Implications and perspectives

This study employs the stochastic framework to assess the influences of climate impacts on biofuel production and cropping decisions. The results show that biofuel production would be effectively promoted in the face of high supportive prices and such efficiencies can only be achieved by constant biomass supply. However, since the farmers are likely to change farming decisions when they expect or perceive climate-induced impacts on crop yield and water distribution that is changing their expected income from harvest. Therefore, the gains from bioenergy production and emission reduction cannot be treated as a net benefit; rather, to reflect the total welfare of biofuel production, the loss of conventional from conventional commodities induced by uncertain climate impacts should be incorporated. Thus the implementation of input-monitoring system and immediate transfer data associated with agricultural activities to biofuel producers can greatly improve the production portfolio.

It is also noticed that such an analytical framework should be applied to a small economy such as Singapore, Taiwan, or Hong Kong, for whose supply has a small share of international agricultural markets. For large economies such as Brazil, Australia, and the United States, the substantial change in land use should be endogenously incorporated into the study.

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Author’s contributions

Dr Chih-Chun Kung designed the study and simulate the programming model. Dr Binbo Zheng collected the data and performed the data analysis. Dr Hailing Li conducted the result analysis and prepared tables and figures. Dr Shan-Shan Kung summarized the results and drafted the manuscript.

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