Sustainable Bioenergy Use and Climate Change in China

- A Spatial Agent Model for the Case of Jiangsu Province

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Eidesstattliche Versicherung

Declaration on oath

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertationsschrift selbst verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

I hereby declare, on oath, that I have written the present dissertation by my own and have not used other than the acknowledged resources and aids.

Kesheng Shu, Hamburg, den 18. Nov. 2014

I dedicate this thesis to
my family, my wife Na Yang
for their constant support and unconditional love.
I love you all dearly.

Abstract

In the context of climate change and energy crisis, bioenergy, which accounts for the largest share of renewable energy in the global energy mix, has drawn considerable attention from an increasing number of countries. While its potential to curb greenhouse gas emissions and to provide energy has been widely acknowledged, concerns over the side effects of bioenergy are still being voiced. In particular, its perceived threats on food security and local ecosystems have largely impeded its development, which is best exemplified by the role that bioenergy takes in the EU's growth strategy of "Europe 2020". This fact provided the motivation for the reflections presented in this thesis on how to realize a sustainable development of the bioenergy industry.

To answer this question, we have selected a coastal province in eastern China as the region in which to conduct our study. China is simultaneously the most populated country and the largest GHGs emitter in the world. It can, therefore, be expected that the entire international community can learn some valuable lessons from the practical experience that China has gathered in the field of bioenergy.

Following a brief outline of the background information on our research in the initial two chapters, Chapter 3 frames the structure of the bioenergy industry and clarifies the role of each actor. Depending on their relative importance in the industry, these actors can be assigned to one of the two categories of stakeholders: central or peripheral. Based on the local practice, we present the construction process of the bioenergy industry in China from both the supply side and the demand side. This descriptive analysis is intended to help the reader form a general understanding of the bioenergy industry in China, on which our subsequent quantitative analysis is based.

Chapter 4 focuses on farmers as one of the central stakeholders that are located at the upstream of the bioenergy supply chain. We develop a biomass feedstock provision model compiled with GAMS to simulate the responsive behaviors of farmers – the agents in our spatial-agent dynamic model – to the challenges arising from emerging energy crops. Using

this model, we delineate land use changes after the insertion of the bioenergy industry. We further fix the sources of the promising biomass feedstock, with the straws of conventional crops accounting for 85% of feedstock and energy crops for the remaining 15%. In view of the geographical characteristics of the region, the northern part of Jiangsu is recommended to accommodate an extensive cultivation of energy crops in the long run. Furthermore, our model also confirmed the positive role of reclaimed mudflats as a candidate for the arable land resource that is capable of alleviating land use conflicts between conventional crops and energy crops.

In analogy to Chapter 4 focusing on farmers, Chapter 5 concentrates on haulers and bioenergy plants operators, which are the other two actors belonging to the category of central stakeholders. Based on the data on biomass feedstock provision predicted by the model described above, we deliberately calibrate the optimizing model of bioenergy industry infrastructure to stimulate their respective performances. As a result we discovered a general pattern in the modeled distribution of bioenergy plants: due to the higher transportation cost of biomass feedstock than of bioenergy products, bioenergy plants opt to be situated more closely to the sources of biomass feedstock than to the consumption centers of bioenergy products. In terms of the specific distribution, the model projects that up to 44% of biorefineries and 62% of power plants with the largest scale should be located in northern Jiangsu. These figures support the government’s decision to turn the area into a production basis for bioenergy, as outlined in the official development plan. Additionally, we evaluate two proposed policies designed to relieve the pressure of bulky biomass transport on local logistic systems and to shorten the regional development disparity among three sub-regions of the region studied.

By combining the above two independent but related models in Chapter 6, we arrive at a decision support system for the bioenergy industry. This system takes into account the whole bioenergy supply chain. Unlike each of the separate sub-models presented in previous chapters, the integrated model adequately depicts the interactions among the upstream and downstream of the bioenergy supply chain. Furthermore, it also describes their feedback to peripheral stakeholders such as the government, local residents, NGOs and other lobbying groups, which do not form part of the supply chain but influence the general setting for the bioenergy industry. Using this model as our analytical tool, we examine two policies aiming to promote the bioenergy industry: a comprehensive policy (a favorable taxation) and a targeted policy (a financial subsidy). Generally speaking, despite the fact that both supportive measures could significantly boost the development of the industry without necessarily jeopardizing food security, their effectiveness relies to a great extent on the scale and the objectives of these measures taken.

In the last chapter, we return to our qualitative analysis. This time, however, we widen its temporal and spatial scope. First, we construct a conceptual model describing the cascade use and recycling of biomass resources. Then we compare the short-term and the long-term incentive mechanisms involved. Finally, we apply Porter's diamond model to analyze separately all the factors constituting the advantages of the bioenergy industry. We argue that an unprecedented opportunity for bioenergy industry development has come. The fundamental actors driving the development of the industry are professional bioenergy firms boasting clearly defined and well-enforced property rights, good supervision mechanisms, advanced technological background and effective management methods. Since the bioenergy industry is mostly oriented towards the domestic market, it is likely to become more competitive with the formation of an industrial cluster focused on bioenergy or by receiving appropriate support from the government. The government's intervention is justified in this context by the government’s supervisory duties, legislative duties and its responsibility to provide favorable incentives.

In this study, we have successfully built an integrated model covering all the actors of the bioenergy industry and proposed a sustainable development strategy for the industry in China. Nevertheless, the study has several limitations that need be overcome before it can be extended to other regions. Firstly, due to the lack of high-quality field data of energy crops plantations, the uncertainties regarding actual agricultural operations and the resultant potential ecological risks cannot be fully reflected in our study. Secondly, only bioethanol and biopower have been included in the mathematical model. In view of the wide variety of biomass conversion routes, more bioenergy products should be included in future models.

Zusammenfassung

Vor dem Hintergrund des Klimawandels und der Energiekrise hat Bioenergie in einer wachsenden Zahl von Ländern in letzter Zeit beträchtliche Aufmerksamkeit gewonnen. Zum weltweiten Energiemix trägt sie bereits heute den größten Teil bei. Zwar wird das Potenzial von Bioenergie, zu einer Reduktion der Treibhausgasemissionen beizutragen, weithin anerkannt; doch werden immer noch Bedenken in Hinblick auf ihre Nebenwirkungen geäußert. Insbesondere die befürchteten Gefahren für die Ernährungssicherheit und lokale Ökosysteme behindern die Entwicklung der Bioenergie erheblich, was wohl am besten anhand der Rolle veranschaulicht werden kann, die der Bioenergie in der Entwicklungsstrategie „Europa 2020“ durch die EU zugeschrieben wird. Vor diesem Hintergrund behandelt die vorliegende Dissertation die Frage, wie eine nachhaltige Entwicklung der Bioenergieindustrie erreicht werden kann.

Zur Beantwortung dieser Frage wurde eine küstennahe Provinz im Osten Chinas als Untersuchungsgebiet ausgewählt. China ist das bevölkerungsreichste Land und der größte Treibhausgasemittent der Welt. Es kann daher davon ausgegangen werden, dass die gesamte Völkergemeinschaft einige wertvolle Lehren aus den praktischen Erfahrungen ziehen kann, die China auf dem Gebiet der Bioenergie gesammelt hat.

Im Anschluss an eine kurze Darstellung des Hintergrunds unserer Untersuchung in den ersten beiden Kapiteln wird im dritten Kapitel die Struktur der Bioenergiebranche skizziert und die Rolle der einzelnen Akteure beschrieben. Abhängig von deren jeweiliger Bedeutung für die Branche können diese Akteure als entweder Haupt- oder Nebenakteure klassifiziert werden. Ausgehend von der lokalen Praxis stellen wir die Entwicklung der Bioenergiebranche in China sowohl auf der Angebots- als auch auf der Nachfrageseite dar. Diese deskriptive Analyse soll dem Leser ein Grundverständnis der Bioenergiebranche in China vermitteln, auf dem die anschließende quantitative Analyse aufbaut.

Das vierte Kapitel beschäftigt sich mit den Landwirten, die als zentrale Akteure am Anfang der Bioenergie-Wertschöpfungskette stehen. Mit Hilfe von GAMS entwickeln wir ein Modell

zur Bereitstellung der Biomasserohstoffe, um das Reaktionsverhalten der Landwirte (den Akteuren in unserem dynamischen räumlichen Akteursmodell) auf die Herausforderungen zu simulieren, die mit dem Aufkommen der Energiepflanzen verbunden sind. Unter Verwendung dieses Modells skizzieren wir die durch die Bioenergiesparte ausgelösten Veränderungen im Bereich der Landnutzung. Hierbei legen wir die Anteile für konventionellen Anbau und Energiepflanzen an der gesamten landwirtschaftlichen Produktion auf 85% und 15% fest. Aufgrund der geographischen Beschaffenheit der Region wird für den nördlichen Teil von Jiangsu langfristig eine extensive Bewirtschaftung mit Energiepflanzen empfohlen. Darüber hinaus wurde mit Hilfe unseres Modells die positive Rolle urbar gemachten Wattenmeers als Ressource einer möglichen Entschärfung von Landnutzungskonflikten zwischen konventionellen und Energiepflanzen bestätigt.

Analog zum Fokus des vierten Kapitels auf Landwirte konzentriert sich das fünfte Kapitel auf Spediteure und die Betreiber von Bioenergieanlagen, die beide ebenfalls zu der Gruppe der Hauptstakeholder gehören. Ausgehend von den Angaben zur Bioenergie-Versorgungskette, die sich aus Simulationen mit dem oben beschriebenen Modell ergeben, justieren wir das Optimierungsmodell für die Infrastruktur der Bioenergiebranche im Sinne einer Förderung der jeweiligen Leistungen. Als Ergebnis wurde ein allgemeines Muster im Hinblick auf die räumliche Verteilung von Bioenergieanlagen beobachtet: Da die Transportkosten von Biomasserohstoffe höher sind als die von Bioenergieprodukten, bevorzugt das Modell eine Entscheidung für die Platzierung von Bioenergieanlagen nahe bei den Rohstoffquellen gegenüber Nähe zu Konsumzentren. Hinsichtlich der genauen räumlichen Verteilung errechnet das Modell, dass bis zu 44% der Bioraffinerien und 62% der größten Kraftwerke im nördlichen Teil von Jiangsu errichtet werden sollten. Diese Zahlen bekräftigen die Entscheidung der Regierung, die Gegend zu einen Standort der Bioenergieproduktion zu machen, was auch im offiziellen Entwicklungsplan der Region zu finden ist. Zusätzlich werten wir zwei vorgeschlagene Handlungsweisen aus, die zur Reduktion der Auswirkungen sperriger Biomassetransporte auf die lokale Logistikinfrastruktur sowie zur Verringerung der Entwicklungsunterschiede zwischen drei Gegenden innerhalb der betrachteten Region beitragen sollen.

Eine Kombination der beiden oben beschriebenen voneinander unabhängigen aber dennoch miteinander verwandten Modelle im sechsten Kapitel führt zu einem Entscheidungsunterstützungssystem für die Bioenergiebranche. Das System berücksichtigt die gesamte Bioenergieversorgungskette. Anders als die in den vorangegangenen Kapiteln beschriebenen Untermodelle bildet das integrierte Modell das Zusammenspiel zwischen den vorgelagerten und den nachgelagerten Märkten innerhalb der Bioenergiebranche hinreichend ab. Darüber hinaus beschreibt es deren Rückkopplung mit den Nebenstakeholdern, zu denen die Regierung, Bewohner, NGOs und andere Lobbygruppen gehören. Diese sind nicht Teil der Versorgungskette, haben aber einen Einfluss auf die Rahmenbedingungen der Bioenergiebranche. Unter Zuhilfenahme unseres Modells als analytisches Instrument untersuchen wir zwei Ansätze zur Förderung der Bioenergieindustrie: Eine umfassende Politik (günstige Besteuerung) und eine zielgerichtete Politik (finanzielle Förderung). Im Allgemeinen hängt die Effektivität beider Ansätze größtenteils vom Ausmaß und von den Zielsetzungen der getroffenen Maßnahmen ab. Die Herausforderung besteht darin die Förderungsmaßnahmen so auszurichten, dass sie die Branche stärken ohne die Nahrungsmittelsicherheit zu gefährden.

Im letzten Kapitel kehren wir zur qualitativen Analyse zurück. Diesmal weiten wir jedoch ihren zeitlichen und räumlichen Rahmen aus. Zunächst entwickeln wir ein konzeptionelles Modell, das die Kaskadennutzung und das Recycling von Biomasseressourcen beschreibt. Daraufhin vergleichen wir die damit verbundenen kurzfristigen und langfristigen Anreizmechanismen. Zum Schluss wenden wir Porters Diamantenmodell an, um all jene Faktoren gesondert zu analysieren, die für die Bioenergiebranche Vorteile bedeuten. Wir legen dar, dass sich derzeit eine noch nie dagewesene Chance für die Entwicklung der Bioenergiebranche bietet. Bei den Hauptakteuren, die die Entwicklung der Branche antreiben, handelt es sich um professionelle Bioenergieunternehmen, die über klar definierte und gut durchsetzbare Eigentumsrechte, etablierte Kontrollmechanismen, einen fortgeschrittenen technologischen Hintergrund und effektive Managementmethoden verfügen. Da die Bioenergiebranche vor allem auf den heimischen Markt ausgerichtet ist, wird sie durch die Bildung eines Branchenclusters oder durch angemessene Förderung durch die Regierung wahrscheinlich wettbewerbsfähiger. Ein Eingreifen der Regierung ist in diesem Zusammenhang durch deren Aufsichtspflicht, deren legislative Aufgaben und deren Zuständigkeit, finanzielle Anreize zu schaffen, gerechtfertigt.

In dieser Studie ist es uns gelungen, ein integriertes Modell zu entwickeln, das alle Akteure der Bioenergiebranche umfasst. Wir haben weiterhin eine Strategie zur nachhaltigen Entwicklung der Branche in China ausgearbeitet. Dennoch hat die Studie auch einige Beschränkungen, die überwunden werden müssen, bevor sie auf andere Regionen übertragen werden kann. Zum Einen können die Unsicherheiten hinsichtlich der tatsächlichen landwirtschaftlichen Erzeugung und den aus dieser resultierenden Umweltrisiken in dieser Studie aus Ermangelung hochwertiger Felddaten im Hinblick auf Energiepflanzenplantagen nicht voll und ganz reflektiert werden, zum Anderen wurden in dem mathematischen Modell nur Bioethanol und Biostrom berücksichtigt. Angesichts der großen Bandbreite an Wegen der Biomasse-Konversion sollten in künftige Modellen weitere Bioenergieprodukte eingebaut werden.

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Abbreviations

ABM	Agent-based model
AFOLU	Agriculture, forestry and other land-use
BioDSS	Bioenergy industry development decision support system
CCS	Carbon capture sequestration
CNDRC	China National Development and Reform Commission
CNPC	China National Petroleum Corporation
EOPGJP	Executive Office of People's Government of Jiangsu Province
GAMS	General algebraic modeling System
GHGs	Greenhouse gases
GIS	Geographic Information System
GLUE	Global land-use and energy model
IBSAL	Integrated biomass supply analysis and logistics model
IEA	International Energy Agency
IPM	Integrated Pest Management
ISCC	International Sustainability and Carbon Certification System
LCA	Life cycle analysis
MF	Model Forest
MOF	Ministry of Finance
Mt	Million tonnes
Mtce	Million tonnes of coal equivalent
Mtoe	Million tonnes of oil equivalent
P.R.C.	People’s Republic of China
PPP	Plant Protection Products
RELPRC	Renewable Energy Law of P.R.C
RF	Radiative forcing
RPS	Renewable Portfolio Standard
SCE	Standard coal equivalent
SCM	Supply chain management
SD	System dynamics
Sinopec	China Petroleum and Chemical Corporation
SOM	Soil organic matter
SRC	Short Rotation of Coppice
SSEPP	State Scheme of Extensive Pilot Projects on Bioethanol Gasoline for Automobiles
UNFCCC	United Nations Framework Convention on Climate Change
YRDEC	Yangtze River Delta Economic Circle

1 Introduction

1.1 Research Background

1.1.1 Climate change and GHGs emission mitigation

Although a small group of people still insist on their suspicion of the reality of climate change, many of the observed changes since mid-19th century have suggested that warming of the climate system is unequivocal. The evidence includes the warmed atmosphere and ocean, the diminished amounts of snow and ice, the risen sea level and the increased concentrations of greenhouse gases (GHGs).

Natural and anthropogenic substances and processes are believed to be the drivers of climate change as they can alter the Earth's energy budget. Radiative forcing (RF) is widely adopted to quantify the change in energy fluxes and the largest contribution to total RF is caused by an increase in the atmospheric concentration of CO_2 since 1750. In the recent years, along with more detailed and longer observations and improved climate models as well as a better understanding of the climate system and its recent changes, it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century. In terms of the sources of GHGs, energy production and agriculture, forestry and other land-use (AFOLU) are the two leading sectors of GHGs (34% and 24% respectively), and the energy sector and transportation dominating the global soaring trend (IPCC, 2013).

As continued emissions of GHGs will cause further warming and changes in all components of the climate system, limiting climate change will require substantial and sustained reduction of anthropogenic GHGs emissions. One goal already accepted by the international community is to keep the global temperature change in this century caused by anthropogenic GHGs emissions less than 2℃ relative to pre-industrial levels. This target, according to the latest calculation, is characterized by atmospheric concentrations in 2100 of about 450 ppm CO_2eq (IPCC, 2014). Actually, the level of anthropogenic emissions is heavily dependent on a group of factors, including population, the structure of the economy, income and income distribution, policy, patterns of consumption, investment decisions, individual and societal behaviors, the state of technology, availability of energy sources and land-use change. Correspondingly, the promising measures to curtail the GHGs emission have to be derived from the reform of these factors. Among them, bioenergy, owning the biggest share in total global energy supply from renewable energy sources, have attracted much research interest on GHGs emission mitigation. Especially, the bioenergy coupled with CCS (carbon dioxide capture and storage), so called BECCS technology, features prominently in long-run mitigation scenarios. This new technology can not only reduce CO_2 emissions by storing carbon in long-term geological sinks, but continually sequester CO_2 from the air through non-stopped and repetitive regeneration of biomass resource feedstock.

China, as the most populous developing country, has contributed 26% of global CO_2 emission in 2010, which is on the top of the emission list. Even though we put the trade factor into consideration, China still has surpassed the U.S. and ranked the first, emitting 21.9% of the total amount. However, if we consider the historical responsibility, that is the accumulation of CO2 emissions over time, China's contribution falls down to the second place (about 12%) with the U.S. leading others. Moreover, once the per capita emission is examined, China slips into the 2nd place, locating after all industrialized countries listed in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC) and some developing countries (U.S. Energy Information Administration, 2014).

In order to perform its international obligation for curtailing its CO_2 emission and realize sustainable development, China has adopted several strategies in recent years to cope with climate change. Among these, utilization of bioenergy is one of the most important measures. China is globally the third-largest producer and consumer of bioethanol. According to the actual situation of utilization in China, the biomass is divided into five types: straw, manure, forest and wood biomass byproducts, municipal waste and urban wastewater. The potential quantity of all biomass byproduct energy in 2004 was 3 511 Million tons coal equivalent (Mtce), and the acquirable quantity was 460 Mtce. Among that, crop residues account for 38.9%, followed by forest wood (36.1%), dung (22.1%), city rubbish (1.9%) and wastewater (1.0%) (Shen et al., 2010).

1.1.2 Energy security

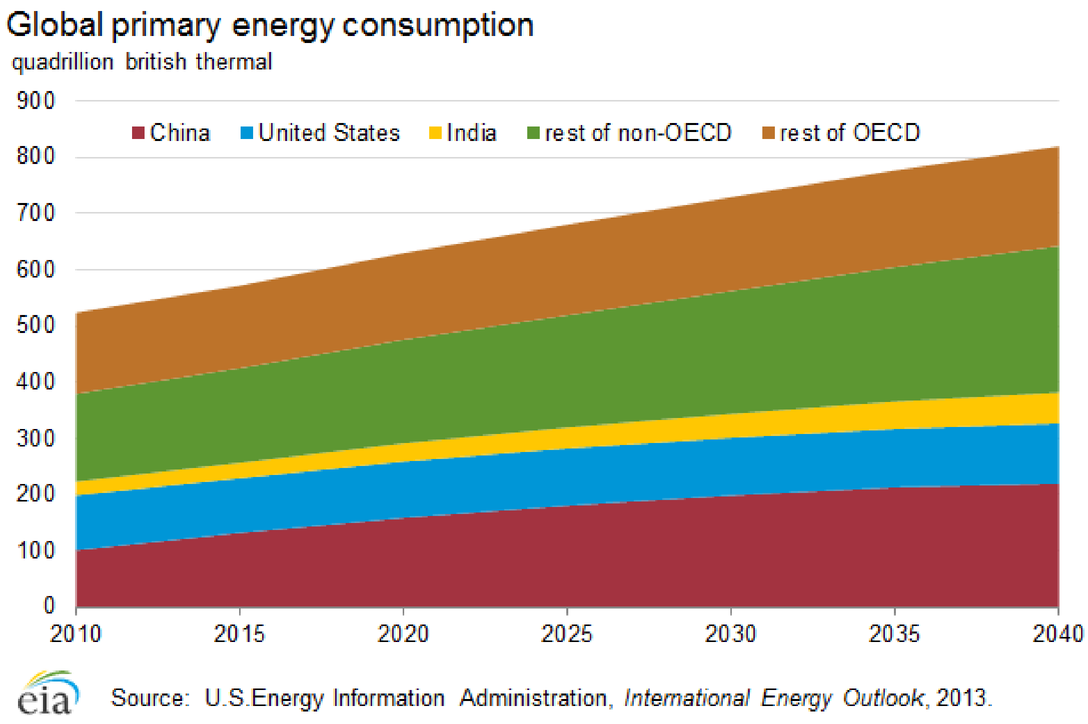


Figure 1-1 Global primary energy consumption

Along with a thrilling two-digital growth of its GDP between 2000 and 2011, China's appetite for raw materials, especially for fossil fuels, has endured an astonishing increase. In 2010, China became the largest global energy consumer, accounting for about half of global coal consumption and being the world's second-largest oil consumer just behind the U.S. (Figure 1-1). In its total primary energy consumption in 2011, coal occupied the vast majority (69%), nearly four times as much as the second largest source- oil (18%). Following the predominant two fossil fuels, hydroelectric sources (6%), natural gas (4%) and nuclear power (nearly 1%) ranks the third, fourth and fifth place respectively.

In light of such energy consumption structure and its limited energy production capability, it is evident that China's domestic energy production growth cannot keep pace with its energy demand growth. This judgement implies that a continuous rise of China’s dependency on abroad resources, such as crude oil, is unsustainable. In 2009, China was the second-largest net oil importer in the world and is projected to surpass the U.S., becoming the top in 2014 (U.S. Energy Information Administration, 2014). High reliance on oil imports has, on the one hand, consumed China's large amount of diplomatic resources; on the other hand, even dragged China into territorial disputes with its neighbors. With the aim of strengthening the state energy security, shifting from traditional fossil fuels to renewable energies could be one feasible and effective solution. Bioenergy, as an indispensable component of renewable energy, deserves high attention.

1.1.3 Development strategy of renewable energy and the prospect of bioenergy

In China, the early laws for encouraging the development of renewable energy can be traced back to 1995. These laws include "*Electricity law of the People's Republic of China (P.R.C.)*"(1995), "*Energy conservation law of P.R.C*" (1997) and "*Air Pollution Prevention law of P.R.C*" (2000) (Peidong et al., 2009). Until 2005, the first specific legislation of renewable energy, "*Renewable Energy Law of P.R.C*" has been published. In 2007, China issued the "*Long-term National Economic and Social Development Strategy*", which set the contribution of renewable energy to 2020's primary energy consumption to 15% (China National Development and Reform Commission 2007).

Furthermore, considering its booming and promising prospect, the Chinese government has issued a specialized development plan exclusively for the bioenergy industry across its 12th five-year period (2011-2015). In "*The 12th Five-year Development Plan of Bioenergy*", the main utilization directions of biomass and the corresponding bioenergy products are selected and confirmed. Meanwhile, the development goal for each bio-product has also been listed out (Table 1.1). Once this goal is achieved, 33 million tons of CO_2 and 2.4 million tons of SO_2 can be curtailed compared to the current energy utilization structure (Zhuang et al., 2010).

1.1.4 The existing problems of bioenergy utilization

Although China has achieved many accomplishments in biomass development so far, some problems still exist. For example, the conflict of land, water, labor and capital between bioenergy crops and food crops is one of the largest obstacles (Schneider and McCarl, 2003). Besides the common barriers, the site-specific natural, social and economic factors have deeply separated China from most of other countries in reference to bioenergy. Firstly, the stress of biomass feedstock supply is much tenser in China than in most other countries. As China uses only 7% of the global arable land to feed 22% of the world’s population, securing

Table 1-1 The planned development goal of main bioenergy products

Bio-products and their sources	Utilization scale		Annual output		Coal equivalent
	Amount	Unit	Amount	Unit	10^6 t/year
1. Power Generation	**13**	10^6KW	**78**	10^9kwh	**24.3**
Agriculture and forestry	8	10^6KW	48	10^9kwh	15
Biogas	2	10^6KW	12	10^9kwh	3.7
Municipal waste	3	10^6KW	18	10^9kwh	5.6
2. Biogas			**22**	10^9m^3	**17.5**
Household	50	10^6households	19	10^9m^3	15
Large scale agricultural residues	6000	terminals	2.5	10^9m^3	2
Industrial organic wastewater and sewage treatment plant sludge	1000	terminals	0.5	10^9m^3	0.5
3. Biomass Solid Fuel	**10**	10^6t			**5**
4. Biomass Liquid Fuel	**5**	10^6t			**5**
Fuel ethanol	4				3.5
Biodiesel and aviation fuel	1				1.5
Total					**51.8**

(Data source: "*The 12th Five-year Development Plan of Bioenergy*")

food supply is an utmost important issue. In this context, the competition for limited agricultural resources between bioenergy crops and traditional crops may perform strongly. Secondly, scattered peasant farmers in China are not ideal for energy crop's introduction as it needs large-scale commercial plantation. Besides that, the hardly convened power of farmers hinders the balance of market power between the biomass supplier and consumer. Thirdly, although non-legal binding development plans have been published, the development mechanism of biomass is unsound due to the scarcity of tailored policy incentives. For example, the special capital subsidies, low VAT rate, low duty rates on biomass equipment or parts and fair pricing mechanism for biomass power generation are abstained (Shen, Liu, 2010).

In order to maximize its positive roles in combating climate change and promoting state energy security while decreasing its negative side-effects on society and environment, conducting a research on the bioenergy industry construction in China is necessary and meaningful.

1.2 Objective and research questions

No matter comparing from the sources, conversion pathways or utilization directions, the bioenergy industry is always the most complicated energy transition system among the portfolio of renewable energies. As it is relevant to many actors in the human-earth system, this research is destined to be a comprehensive and cross-disciplinary one.

In general, this project is aiming to design a tailored sustainable development approach for the bioenergy industry in China. Following the whole life cycle of bioenergy, this research seeks to combine the existing principles, criteria and requirements of the International Sustainability and Carbon Certification (ISCC) system with the local situation of China. Through the integration of qualitative and quantitative analysis, that is, setting up both a conceptual and a computational model, this project is devoted to optimizing the distribution of biomass feedstock and bioenergy infrastructure. Furthermore, it will propose innovative measures and streamlined strategies for regional governance towards each sector of bioenergy supply chain, which meet the requirements of technical feasibility, economic viability, environmental sustainability and societal acceptability.

Such research objective entails the following specific research questions which the thesis attempts to discuss:

- What are the interactions of bioenergy to the actors of the human-earth system?
- What does the structure of the bioenergy industry in China look like?
- How to manage bioenergy supply chain?
- Is it preferable to introduce energy crops? If yes, which kinds of energy crops are suitable for introducing?
- What are the optimal land use patterns under different biomass demand levels?

- Can mudflats play a positive role in alleviating land use conflict between energy crops and conventional crops?
- Following an optimal biomass feedstock distribution, how to arrange the bioenergy infrastructure and the related transportation network?
- How to envision the utilization methods of biomass feedstock in the future? Biomass-based power plant and biorefinery, which is more suitable for China?
- Is biomass pretreatment process worth introducing to China?
- What does a bioenergy industry decision support system look like?
- Can the initiative of combating climate change play a big role in promoting bioenergy industry?

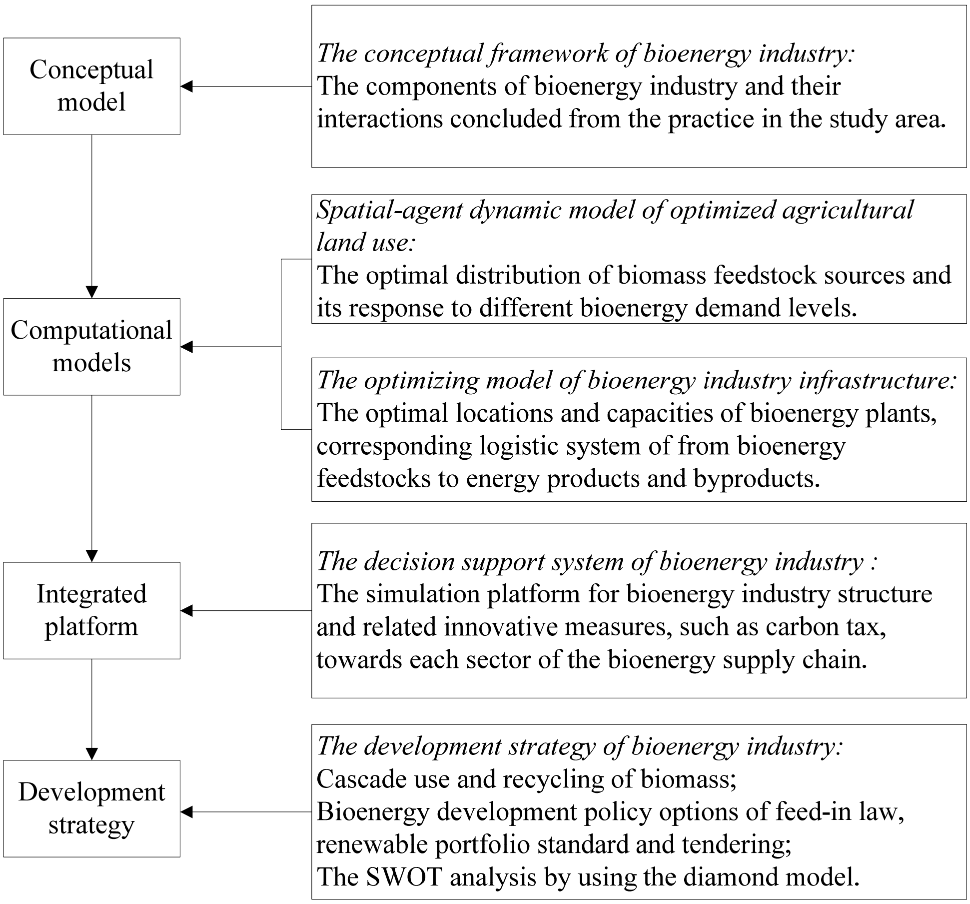
1.3 Thesis framework

In order to achieve the above goal and answer such questions, our research will follow the below technical route (Figure 1-2):

Along with the presented technical route, this research includes four steps:

1. Clarifying the components of the bioenergy industry retrieved from local practice in the Jiangsu province and shaping the conceptual framework of the industry.

On the basis of understanding the status of bioenergy in the human-earth system composed of natural resources, human needs, societal stability and climate change, this research starts from scrutinizing the bioenergy development practice in our study area, the Jiangsu province. In accordance with the whole life cycle of bioenergy utilization combined with Jiangsu's experience, we delineate a conceptual framework of bioenergy industry for China and discuss the biomass feedstock supply management. This part qualitatively presents us a complete picture of how should bioenergy industry in China look like.



The conceptual framework of bioenergy industry:
The components of bioenergy industry and their interactions concluded from the practice in the study area.

Spatial-agent dynamic model of optimized agricultural land use:
The optimal distribution of biomass feedstock sources and its response to different bioenergy demand levels.

The optimizing model of bioenergy industry infrastructure:
The optimal locations and capacities of bioenergy plants, corresponding logistic system of from bioenergy feedstocks to energy products and byproducts.

The decision support system of bioenergy industry :
The simulation platform for bioenergy industry structure and related innovative measures, such as carbon tax, towards each sector of the bioenergy supply chain.

The development strategy of bioenergy industry:
Cascade use and recycling of biomass;
Bioenergy development policy options of feed-in law, renewable portfolio standard and tendering;
The SWOT analysis by using the diamond model.

Figure 1-2 The technical route of the research

2. Constructing a spatial-agent dynamic model of optimized agricultural land use to simulate the distribution of biomass feedstock sources in the Jiangsu province

Out of its excellent performance on complex and large scale modeling applications, we choose GAMS software to set up a non-linear spatial-agent dynamic model. This model is designed to present an optimal temporal and spatial distribution of biomass feedstock by simulating each agent's decision making on limited agricultural resources allocation among candidate crops across a period of twenty years. Besides of showing the optimal land use pattern, this model can also be applied to observe the land use change under different biomass demand scenarios.

3. Developing the optimized model of bioenergy industry infrastructure to allocate the bioenergy plants and design the correspondent transportation system

Following the above model, another optimization model of bioenergy industry infrastructure will be constructed. This model is to determine the optimal locations and capacities of two types of bioenergy plants (biomass-based power plants and biorefineries), and the correspondent delivery system of biomass feedstock, bioenergy products and byproducts transportation. The model is fairly helpful in allocating efficient and cost-effective bioenergy industry infrastructures which will bring a profound influence on the revival of rural areas in China.

4. Building a decision support system for the bioenergy industry to analyze policy effects quantitatively

By the integration of above two mathematical sub-models, a decision support system describing all sections of supply chain of the bioenergy industry in China will finally be built. Running on this simulation system, conducting a quantitative assessment of policy effects becomes possible. In this research, we will explore two policies, the targeted governmental subsidies and universal carbon tax.

5. Proposing a sustainable development strategy of the bioenergy industry

Combined with all the findings in the previous steps, the conclusion part of the study discusses the comprehensive strategy of the bioenergy industry sustainable development. We will first propose the concept of cascade use and recycling of biomass resources, and then explore the relations of the incentive mechanism in the short and the long term. In the end, Porter's diamond model is applied to analyze the bioenergy industry’s strength, weakness, opportunity and threats, which forms the competitiveness of the industry.

1.4 Research methods

This research is conducted across several disciplines, such as Geographic Information Systems (GIS), agricultural economics, industrial economics, human geography and operations research. By combining field research and indoor analysis, our study emphasizes both theoretical and practical issues. It is a mixture of qualitative and quantitative measurement and a combination of spatial and temporal dimensions. Specifically, the research methods entail:

1. Agent-based model

An agent-based model (ABM) is a class of computational models for simulating the actions and interactions of autonomous agents (either individual or collective entities, such as organizations or groups) with a view to assessing their effects on the system as a whole. This research depicts each county as an agent and observes its behavior. It is assumed that, all the farmers (in the optimized model of agricultural land use) and all the bioenergy plants (in the optimized model of bioenergy industry infrastructure) in one county are assembled as one agent.

2. System dynamics

System dynamics (SD) is an approach to understanding the performance of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system. This method applied to our research is to examine the change of land use and the distribution of bioenergy plants over a timeframe of twenty years.

3. Life cycle assessment

Life-cycle assessment (LCA) is a technique to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e. from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, to disposal or recycling). Our study applies the concept of "life from cradle to grave" to our bioenergy industry structure analysis and sorts out all the stakeholders in the whole process of biomass utilization for energy purpose.

4. Time series forecasting

Time series forecasting is a group of techniques of trend extrapolation based on the assumption that "the best estimate for tomorrow is the continuation of yesterday’s trend". Among those, regression analysis is commonly used. This thesis is using such a technique to generate values of some parameters.

1.5 Research innovative points

Based on all the accessible literature, this project is, so far, the first ever study to apply GAMS to create a decision support system for the bioenergy industry development in China.

Unlike most existing quantitative researches on bioenergy, which mimic only parts of the industry, this project covers the whole manufacturing flow of bioenergy products. It particularly examines the interactions of farmers and bioenergy plants operators on the biomass feedstock market.

The simulation results fill the knowledge gap between theoretical analysis on the role of the bioenergy industry in the context of climate change and the local practices in the Jiangsu province. This progress lays a foundation of understanding the status of bioenergy in the complex human-earth system.

Besides that, the framework of the simulation platform can also be extended to include more natural resources, which offer policymakers a powerful analysis tool for assisting the natural resources management.

2 Literature review

2.1 The global biomass potential

The supply of sustainable energy is one of the main challenges that we have to face over the coming decades, particularly because of the need to address climate change. Biomass, the carrier of bioenergy, can make a substantial contribution to supplying future energy demand in a sustainable way. In the past, bioenergy has been utilized in the form of heat for a quite long time in human history. Nowadays, thanks to the development of biomass conversion technology, its form has expanded to electricity and fuels for transportation. So far, it is the largest contributor of the global renewable energy supply (International Energy Agency, 2010).

At present, forestry, agricultural and municipal residues, as well as wastes are the main feedstocks for biomass-based electricity and heat generation. In addition, a very small share of sugar, grain, and vegetable oil crops are used as feedstocks for the production of liquid biofuels. As to the assessment of global bioenergy potential, various researchers have contributed efforts in this field. The earliest specialized biomass potential assessment can be traced back to 1993. Hall et al. (1993) described the potential of biomass based on the principle physical and chemical properties of biomass and the fundamental of photosynthesis. Following that, Yamamoto et al. (1999) had used a SD technique to develop a global land-use and energy model (GLUE) and considered the competition of land use among the bioenergy, food and materials and energy source constraints. Based on the model results, they speculated that in 2100, the ultimate bioenergy potential will reach 277EJ/yr, which promisingly comes from energy crops harvested on surplus arable lands and biomass residues, such as cereal-harvesting residues, animal dung, roundwood felling residues, and timber scrap. Furthermore, Fischer and Schrattenholzer (2001) made a similar assessment by linking the potentials with scenarios of agriculture production and land use in the global energy scenario with high economic growth and low GHGs emissions. They estimated that bioenergy would supply 15% of global primary energy by 2050. In 2003, Berndesa et al. (2003) analyzed the contribution of biomass to the future global energy supply reviewed from 17 papers including the aforementioned ones. Through the review, the authors found out that the projected scale of biomass utilization for energy purpose in 2050 would vary from below 100 EJ/yr to above 400 EJ/yr. They believed the reason of the big difference was large uncertainties of three crucial parameters, land availability and yield levels in energy crop production as well as the substantial variation of the future availability of forest wood and of residues from agriculture and forestry. In order to cluster the reviewed papers, they classified these 17 studies into either demand-driven or resource-focused types. This classification, to some extent, has reflected the two opposite initiatives, considering either from demand side or supply side, of the assessment of bioenergy potential. Following that, Dornburg et al. (2010) revisited the key factors that may influence the potential. They argued water availability, biodiversity, food demand, energy demand and agricultural commodity markets were the interrelated factors. Moreover, they made a sensitivity analysis of the available information to narrow down the range of biomass potentials from 0-1500 EJ/yr to approximately 200-500 EJ/yr in 2050. A year later, Offermann et al. (2011) borrowed the definition of biomass potential (there are four levels: theoretical potential, geographical potential, technical potential and economic potential) from Smeets and Faaij (2007) and concluded that bioenergy would not have the potential to become the major part of the global primary energy supply in the future, although the definite size of the potential was unclear and estimates were widely varied.

Biomass feedstock in China generally comes from the residue from agriculture and forestry processing, covering solid residue, the concentrated organic waste water from the agriculture products processing, crop straw and stalk, human and animal excrement, and urban residential refuse. Although China is in the transition from a traditional agricultural-based society to a modernized industrial-based society, the population residing in rural areas is partly relying on biomass, especially for the residents in remote rural areas. Li et al. (1998) investigated the biomass potential in China systematically and specifically. They adopted the "bottom-up" method to assess the amount and analyze the availability for energy purpose of biomass from the source of straw and stalk, excrement, municipal solid waste, forest and wood residues respectively. In addition, they further set up the first biomass resource database system in China to provide data support for later coming researchers and decision makers. Later, Li et al.

(2005) basically followed the same line and further classified the forest and wood residues in two sub-categories: the ones from efficiency improvement and the others from substitution by other fuels. In addition, they also took waste water and black liquor into consideration. Different from above two studies, Elmore et al. (2008) applied a completely different method. Taking agricultural residue from rice as an example, they tactically used nationwide data sets of net primary production (NPP) to calculate the spatial distribution of rice straw in China for the period 2000-2004. Through a comparison with the results from local investigations, it proved that remote measures of rice straw yield could reasonably replace field investigations on the provincial scale. Along with this way, Jiang et al. (2012a) brought this GIS-based approach a step forward. They took a number of conservation issues, including resources (total amount, spatial and temporal distribution), economy (transportation costs), environment, and technology, into consideration. This approach makes the assessment process to be more realistic and reliable.

2.2 Energy crop plantation

Out of the concern over food security, the claims for upgrading the biofuel production technology from 1st generation to 2nd generation have gained in popularity. Therefore, many countries started to consider the plantation of dedicated energy crops on marginal lands for biomass supply.

As early as in 1930s, switchgrass had firstly come into view on Lincoln, NE, USA. In 1990, its role on offering bioenergy was reaffirmed there. Recently, the US energy department had identified switchgrass as a viable perennial herbaceous feedstock for cellulosic ethanol production (Mitchell et al., 2008). Besides, Walsh et al. (2003) also confirmed another two promising bioenergy crops, hybrid popular and willow, in a modified agricultural sector model (POLYSYS). They set up two scenarios of farm-gate price of biomass, respectively at US$2.44/GJ and US$ 1.83/GJ, and found that a higher farm-gate price intended to encourage the adoption of management practice for higher productivity on Conservation Reserve Program lands. Not only in the U.S., in India Rashmi et al. (2009) had considered kansgrass, a variety of switchgrass, and proposed that instead of planting cereal crops, cultivating energy crops for bioenergy production and exporting the energy may be more beneficial to the country. In Argentina, van Dam et al. (2009) argued that it was difficult to draw a general conclusion whether or not switchgrass was sustainable for one region, because the answer heavily depended on the locally applied agricultural management system. Besides of switchgrass, reed canary grass and miscanthus sinensis are also among the candidate energy crops (Lazdina et al., 2007, Stewart et al., 2009).

Considering China's large population and the incurred food supply pressure, diversifying the sources of biomass feedstock is of full practical significance for this country. With respect to the candidate sources, Huang (2005) selected sugarcane, cassava and sweet potato as the crops suitable for his suggested biofuel production projects in southern China. Different from Huang’s study, Shao and Chu (2008) studied oil-based plants for biodiesel. They selected 10 species out of 1 554 species in China, among which 154 species have oil rich seeds with more than 40% oil content and 30 species have rich biofuel content. In 2010, Li et al. (2010) recommended another five species, Salix, Hippophae, Tamarix, Caragana and Prunus, as dedicated energy crops in China. Tian et al. (2009) estimated that by 2020, the production capacity of bioethanol in China will climb up to 22 million tons should reserved land resources be explored and yield per unit area be improved.

2.3 The role of bioenergy in the human- resource- environment system

As the carrier of bioenergy, biomass is utilized in different forms to meet diverse human demands, such as the need for food, feed, industrial raw material or energy. This renewable energy helps to keep societal stability and alleviate climate change by partly replacing the use of fossil fuels. Conversely, these factors can also promote or hamper the development of bioenergy. The interactions between these actors and bioenergy are part of the human-earth system in which bioenergy stands at the central stage (Figure 2-1). Given above understanding, we will focus on the economic, social and environmental opportunities and challenges of bioenergy development as well as the benefits and negative side effects in such applications. The research of this part can offer a general image of bioenergy in the whole human- resource- environment system and clarify the key points worthy of further research.

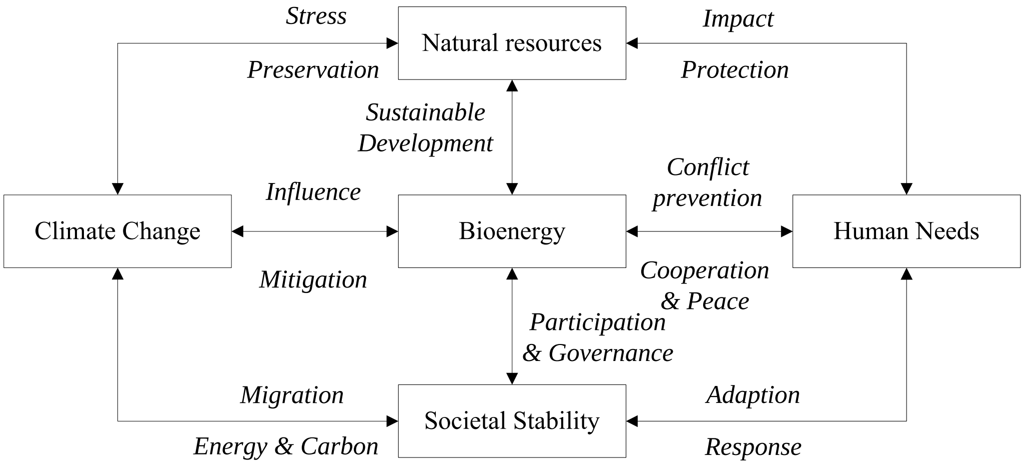


Figure 2-1 Integrated assessment framework with causal links between climate change, natural resources, human needs and societal stability, with possible strategies from the perspective of bioenergy (Adapted from Scheffran & Schilling, 2009)

2.3.1 GHG emissions mitigation

Many studies hold a view that the use of bioenergy has zero net carbon emissions since the emissions released in its utilization for energy are subsequently captured in biomass regrowth. Therefore, using the “carbon-neutral” energy to replace petroleum in the transportation sector and coal in electricity generation can reduce the emission amount of CO_2 to the atmosphere.

In order to accurately assess bioenergy’s substantial potential in GHGs mitigation, the International Energy Agency (IEA) proposed Task 38 titled “GHGs balances of biomass and bioenergy systems”. This project brings together the 12 participating countries’ national programs on GHGs balances for a wide range of biomass systems, bioenergy technologies and terrestrial carbon sequestration. With the perception that bioenergy industry can be regarded as an independent counterpart to the existing agriculture system and the fossil fuel energy system, these studies evaluated the potential of CO_2 emission mitigation by comparing the bioenergy system with either afforestation or fossil fuel energy system (Table 2-1). Even though the research in one group uses the same referencing system, their assessment results are quite different, even in some cases are exclusive to each other. In our view, the discrepancies arise from the inconsistent definitions of research boundary and the diverse geographic features in different research regions.

Table 2-1 Review of selected research papers on the evaluation of the role of bioenergy in GHG emissions mitigation

Selected paper	Methodology	Results
Research field Ⅰ: Bioenergy system versus Afforestation		
Hall and House, 1993	Literature review	The substitution of bioenergy to fossil fuels could be far more effective.
Schlamadinger and Marland, 1996	Graz/Oak Ridge Carbon Accounting Model	Strongly depends on the productivity of land, the current land use pattern, and the efficiency of the applied harvest method.
Sims, 1999	Case study in New Zealand	Afforestation, at the best, can only be a short-term measure.
Hedenus and Azar, 2009	A linear optimization model that links the energy system, an afforestation sector and the pulp and timber market.	Long-rotation forests for the purpose of carbon sequestration will not be cost-effective in the long run under a stringent climate policy.
Rootzen et al., 2010	PRO-COMAP model	In the short term perspective (meaning 30 years), the mitigation potential of long-rotation plantation is desirable. The bioenergy is, however, preferred if a long-term view is taken.
Alig et al., 2010	Forest and Agriculture Sector Optimization Model-Greenhouse gases model	Receipt of carbon-related payments by landowners in forestry and agriculture can have substantial impacts
Research field Ⅱ: Bioenergy system versus Referencing fossil fuel energy system		
Schlamadinger et al., 1997	A standard methodology, emphasis on system boundaries definition	Site-specific
Jungmeier et al., 1999	LCA	In general, the greenhouse gas emissions of bioenergy systems are lower compared to the fossil systems.

Cherubini, 2009	Standard LCA conform to ISO 14040 norms	Site-specific
Research field Ⅲ: Intrinsic components of bioenergy system		
Ⅰ: Energy system versus multi-product crop system: Dornburg et al., 2005	Monte-Carlo analysis	Multi-product crops are not granted for an option to increase the performance of bioenergy systems
Ⅱ: The scale of bioenergy system: Dornburg et al., 2007	A methodology combined a bottom-up analysis of biomass applications, biomass cost supply curves and market prices of land, biomaterials and bioenergy carriers	GHGs emission mitigation costs increase strongly along with the scale of biomass production.
Ⅲ: Biomass carbon cycle: Cherubini et al., 2009	LCA	Site-specific
Ⅳ: Comparison of four candidate bioenergy crops: Hillier et al., 2009	LCA	Miscanthus and Short Rotation of Coppice (SRC) are likely to have a mostly beneficial impact on curtailing GHGs emissions, while oilseed rape and winter wheat have either a net GHGs cost or only a marginal benefit.

Besides CO_2 emission reduction, some researches discussed other issues: Bouwman et al. (2010) concentrated on the nitrogen rather than the carbon cycle in the simulation of biofuel production from energy crops. They estimated that annual production would require an additional 19 Tg of N fertilizer by 2050, causing a global emission of 0.7 Tg of N_2O-N, 0.2 Tg NO-N, and 2.2 Tg of NH_3-N. Bohin (1998), Yu and Peng (2007) introduced the carbon tax in their research. Laurijssen and Faaij (2009) and Pasicko et al. (2009) considered the possibility of certified carbon emission trade on the global level.

2.3.2 Other environmental issues

Besides GHG emissions mitigation, much literature also focuses on other environmental issues. For example, the role of energy crops on soil remedy has been examined. Koffa (1991) emphasized that the introduction of certain kinds of hydrocarbon- and oil-based plant species can remedy more than 5 million ha of degraded soils in the Philippines. Similarly, Chiaramonti et al. (1998) introduced a so-called “DESERESCUE” project, which considers the biomass as a source of both bioenergy and water. They argued that the latter value would be welcomed by many coastal areas of the Mediterranean countries, as well as by other countries sharing the similar situations.

Besides that, soil fertility is also a hot topic. Annex et al. (2007) demonstrated that the emerging markets for bioenergy from cereal crops were creating a time window for the redesign of conventional agricultural system. The eco-friendly and efficient agricultural system of a closed nutrient cycle was envisioned to reduce the energy cost and economic cost of fertilizers and pesticides simultaneously. In particular, he took switchgrass (Panicum virgatum L.) as an example and predicted that such crop could curtail 78% of required N-fertilizer. However, Huggins et al. (2011) doubted that the removal of crop residue from land would substantially decrease the soil organic matter (SOM) which, in turn, could negatively affect the sustainability of agriculture in the long term.

Along with that, a group of researchers have concerns about the change of landscape and biodiversity led by the introduction of energy corps. They believe that the cultivation of energy crops can impact biodiversity both positively and negatively depending on the scales. For example, positive effects of enhanced bio-control services on biodiversity can be observed at the field level, but the extent of such impacts heavily depends on the management, age, size and heterogeneity of the crops. On a regional scale, significant uncertainties exist, and there is a major concern that extensive commercial production could have adverse effects on biodiversity, particularly in areas of high nature conservation value. However, the integration of energy crops into traditional agricultural system could help stimulate the restoration of degraded land and improve biodiversity values (Dauber et al., 2010, Firbank, 2008, Hennenberg et al., 2010, Landis et al., 2008). Additionally, energy crop’s positive role on biotic intrusion prevention and negative influence on the shrinking habitat for wildlife cannot be neglected (Fargione et al., 2009, Witt, 2010).

In addition, land use change, even land use conflict in densely populated nations, has drawn increasing attentions. The introduction of energy crops will, to some extent, occupy the original arable lands for conventional crops. Therefore, the traditional land use pattern faces new challenges, such as food price fluctuation, global warming pollution, deforestation, nutrient runoff, water use and other relevant environmental impacts. One possible way to avoid such problems is to plant energy crops on marginal lands, i.e. the areas poorly suited to conventional crops owing to either low soil fertility or food safety reasons (Ceotto and Candilo, 2011, Dale et al., 2010, Martin and Hopson, 2008).

2.3.3 Socio-economic issues

In addition, bioenergy can also prompt the economical and social improvement at the cost of the associated challenges.

Many studies support the views that each section of life cycle of bioenergy, from biomass feedstock production, transportation, conversion to bioenergy products and byproducts distribution, can generate significant benefits for rural economy and communities. Thornley et al. (2008) conducted a quantitative estimation of the employment of biomass power plants. Domac et al. (2002) (2005) further classified the employment created by bioenergy plants into three kinds:

·Direct employment, resulting from bioenergy plants operation, construction and bioenergy products output;

·Indirect employment, resulting from all activities connected, but not directly related, like supporting industries, services and similar;

·Induced employment, which describes the effects including the higher purchasing power, which is induced by increased earnings from direct and indirect jobs, may also create opportunities for new secondary jobs, which could attract people to stay or even to move in.

Plieninger (Plieninger et al., 2006) conducted his study in Germany and concluded the conditions for a successful production of biomass feedstock. These conditions include economic factors, the forms of public incentive tools, the compatibility with farmers' cultural patterns and psychological aspects. Additionally, they compared small- and large-scale bioenergy plants and claimed the former led to a more comprehensive creation of added value in agriculture and rural areas than the latter.

On the other hand, some researchers have concentrated on a regional scale and explored the role of bioenergy in promoting regional development. Elbakidze et al. (2007) took Murmansk in northwest Russia as a case to apply Model Forest (MF) in a bid to achieve regional sustainable development which based on forest goods, ecosystem service and values. Perez-Verdin et al. (2008) held a similar viewpoint. He analyzed the economic impacts of woody biomass utilization for bioenergy in Mississippi, US in terms of gross output, value-added and also employment. Additionally, Gan and Yu (2008) argued that there was a considerable potential in developing and disseminating household-based technologies, for example the energy-efficient modern biomass stoves, in rural areas of China. This small-scale and scattered way of utilization was believed to produce far more economic, social and environmental benefits than centralized biomass-based power plants. Sharing the same opinion as Gan's of opposing centralized bioenergy usage, Wang (2008) advocated biogas production. He recommend that combined with solar energy and wind energy, the biogas generated by biomass fermentation can basically meet the energy demand in rural and, moreover, biogas can help build a circular economy. By taking local geographic features into consideration, biogas can be used in Tibet, China.

Although the majority of researchers have valued the benefits of bioenergy in regional development, there are still some scientists holding a critical opinion. Kuchler (2010), for example, critically reviewed how energy security-, food and agriculture-, and climate change-oriented international organizations frame bioenergy production in developing countries, e.g. bioethanol production in Brazil. He pointed out that the way in which these global institutions framed bioenergy's role in developing regions had already sufficiently manifested the inequalities in energy supply and environment protection between the "core" and "periphery" countries, and created internal contradictions that perpetuated unequal exchanges embedded in the system.

2.3.4 Sustainable standards and certification schemes for bioenergy

Out of the concerns over potential side effects of large-scale bioenergy production projects, sustainability criteria and certification systems are proposed by some literature so as to guarantee the bioenergy use in sustainable pathways and to “maximize the use of potentials while minimizing risks” (WBGU, 2009).

In a study of the certification system for international biomass trade, Lewandowski and Faaij (2006) listed more than 100 social, economic, ecological and general criteria deliberately selected from existing certification systems, sets of sustainability criteria or guidelines on environmental or social sound management of resources. Markevicius et al. (2010) , on the other hand, reviewed the sustainability criteria of the production and use of liquid biofuels. In his research, 35 criteria were framed in an emerging sustainability assessment framework. Among those, 12 criteria focus on environmental issues, 4 are social related and 1 is about economy. In general, energy balance and GHGs balance were perceived as especially critical, whereas food security ranked comparatively low. In the same research field, Buchholz et al. (2009) did a literature review and drew a similar conclusion: Only two criteria, energy balance and GHGs balance, were perceived as critical. Social criteria and site-specific criteria were ranked low in all attributes.

So far there are already many initiatives to this certification scheme written down on paper. The first legally binding certification system for sustainable biomass and bioenergy is the "*International Sustainability and Carbon Certification* (ISCC)". Established under the framework of a German Law "*Biokraftstoff-Nachhaltigkeitsverordnung*" and supported by German Federal Ministry of Food, Agriculture and Consumer Protection via the Agency for Renewable Resources (FNR), ISCC was approved in 2010 by German Federal Institute for Agriculture and Food (Bundesanstalt für Landwirtschaft und Ernährung, BLE). The system is operational, though still under development. ISCC describes the rules and procedures for certification that are issued by the approved Certification Bodies with the ISCC Label (Seal)[1].

The objectives of the ISCC are the establishment of an internationally oriented, practical and transparent system for the certification of biomass and bioenergy, allowing a differentiation of sustainable from non-sustainable products at different stages of the value chain. Regarding the key issues (reduction of GHGs emissions; sustainable land use; protection of natural

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[1] The following introduction of ISCC system is cited from Scheffran J., 2010. Criteria for a Sustainable Bioenergy Infrastructure and Lifecycle, in: Mascia P.N., Scheffran J.(Eds.), Plant Biotechnology for Sustainable Production of Energy and Co-Products. Springer, Heidelberg, pp. 409- 47.

biospheres; social sustainability), six principles are defined, specified by their respective criteria (see Appendix I). These are categorized as “major musts” (M1 in the table) and “minor musts” (M2 in the table), where, for a successful audit, all major musts and 80% of the minor musts have to be complied with.

ISCC initially is about a central-organized certification system where the standards are meant to be international and valid in all countries and regions that are part of the value added chain. As needed, a national or regional initiative can adapt the ISCC standards to local conditions.

2.4 Some comments on the literature review

Since bioenergy has been seen as a fairly feasible and effective solution to both GHGs emission mitigation and global energy security, the coverage of the concept of bioenergy has evolved a lot from its original definition. The development of modern biomass conversion technology offers an opportunity to diversify the pathways of biomass utilization, meaning the way not only limited to fuel wood for cooking. Partly due to this reason, a consensus on the calculation of biomass potential does hardly exist, although much effort has been pouring on it. In addition, this estimation would appear more complex, should the introduction of energy crops and site-specific geographic features be taken into consideration. Among numerous models for biomass potential calculation, it is too arbitrary to judge which method is the best as each model has its particular application field and corresponding conditions. However, at least, it is confident to say that the models involving local situations are more precise than general ones. Thus, it is meaningful to set up a localized mathematical model for simulating the bioenergy industry in China following a generalized analysis framework.

Besides that, the role of bioenergy in the complex human-earth system has also been explored by a number of studies. Particularly, the benefits and costs bioenergy projects can bring to the regional economy, society and environment have been in-depth reviewed. Among those, energy balance and GHGs balance are repeatedly discussed. Concluded from the experiences gained in advanced countries in terms of bioenergy development, the publication of ISCC certification system is a cornerstone on the way to a sustainable bioenergy industry. Following the spirit of the system, we need to construct a technically feasible, economically viable, environmentally sustainable and socially acceptable bioenergy industry for China. To achieve this goal, it is necessary to set up a mathematical model and apply this model to quantitatively analyze the distribution of biomass feedstock and bioenergy infrastructure, which lays a foundation for proposing innovative measures and streamlined strategies for the stakeholders of the bioenergy industry.

Appendix I Principles, criteria and requirements of the International Sustainability and Carbon Certification (ISCC) system

Principles and types of criteria	Criterion	M1	M2
PRINCIPLE 1: Biomass shall not be produced on land with high biodiversity value or high carbon stock. HCV areas shall be protected			
	Biomass is not produced on land with high biodiversity value.	X	
	Biomass is not produced on highly biodiverse grassland.	X	
	Biomass is not produced on land with high carbon stock.	X	
	Biomass is not produced on land that was peatland in January 2008 or thereafter.	X	
	If land was converted after January 1, 2008, the conversion and the use should not run contrary to principle 1.	X	
	All other production areas of the farm/ plantation comply with the ISCC Principle 1.	X	
PRINCIPLE 2: Biomass shall be produced in an environmentally responsible way. This includes the protection of soil, water and air and the application of Good Agricultural Practices			
Environmental impact assessment and stakeholder consultation	Environmental aspects are considered if planning buildings, drainage etc.	X	
Natural water courses	Natural vegetation areas around springs and natural watercourses are maintained or re-established.		X
Soil conservation and avoidance of soil erosion	Good agricultural practices must be applied with respect to: Prevention and control of erosion, maintaining and improving soil nutrient balance, soil organic matter, soil pH, soil structure, soil biodiversity and prevention of salinisation. A soil management plan aimed at sustainable soil management, erosion prevention and erosion control must be documented. Annual documentation of applied good agricultural practices with respect to the above mentioned aspects must be in place.		X
	Field cultivation techniques used to reduce the possibility of soil erosion.	X	
	Soil organic matter is preserved.	X	
	Organic fertilizer is used according to nutritional requirements of the soil.	X	
	Burning as part of the cultivation process is not allowed	X	

	without permission. Burning as part of land clearance is not allowed.		
Soil organic matter and soil structure	Techniques have been used that improve or maintain soil structure.	X	
	The use of agricultural by-products does not jeopardize the function of local uses of the by-products, soil organic matter or soil nutrients balance. Documentation must be available that the use of by-products does not occur at the expense of the soil nutrient balance, soil organic matter balance or important traditional uses (such as fodder, natural fertilizer, material, local fuel etc.) unless documentation is available that similar or better alternatives are available and are applied.	X	
Ground Water and Irrigation	Mineral oil products and Plant Protection Products are stored in an appropriate manner which reduces the risk of contaminating the environment.	X	
	If ground water is used for irrigation, the producer respects existing water rights, both formal and customary, and can justify the irrigation in light of accessibility of water for human consumption. Local legislation is followed.	X	
	Documentation of water management plan aimed at sustainable water use and prevention of water pollution. Annual documentation of applied good agricultural practices with respect to: efficient water usage, responsible uses of agro-chemicals, waste discharge must be available.		X
	The producer can justify the method of irrigation used in light of water conservation.		X
	To protect the environment, water is abstracted from a sustainable source.		X
Use of Fertilizer	During the application of fertilizers with considerable nitrogen content care is taken not to contaminate the surface and ground water.	X	
	Fertilizers with considerable nitrogen content are only applied on absorptive soils.	X	
	Complete records of all fertilizer applications are available (where, what, how much, date).	X	
	The fertilizer application machinery allows accurate fertilizer application.	X	
	Inorganic fertilizers are stored in a covered, clean and dry area.		X
	Fertilizers are stored in an appropriate manner, which reduces the risk of contamination of water courses.	X	
	Fertilizer is used according to an input/output balance.	X	
	The use of raw sewage sludge is not allowed.	X	
	Assistance with implementation of IPM systems has been		X

Integrated Pest Management (IPM)	obtained through training or advice.		
	The producer can show evidence of implementation of at least one activity that falls in the category of "Prevention".		X
	The producer can show evidence of implementation of at least one activity that falls in the category of "Observation and Monitoring".		X
	The producer can show evidence of implementation of at least one activity that falls in the category of "Intervention".		X
Use of Plant Protection Products (PPP)	Staff dealing with plant protection products is competent.	X	
	Producers only use plant protection products that are registered in the country of use for the target crop where such official registration scheme exists.	X	
	The producer follows the label instructions.	X	
	All application equipment is calibrated.	X	
	Invoices of registered plant protection products are kept.		X
	If there are local restrictions on the use of plant protection products they are observed.	X	
	All the plant protection product applications have been recorded (where, when, what, how much, why, who).	X	
	Surplus application mixes or tank washings is disposed of in a way not to contaminate the ground water.	X	
Plant Protection Product Storage	Plant protection products are stored in accordance with local regulations in a secure, appropriate storage. Potential contamination of the ground water must be avoided.	X	
	There are facilities for measuring and mixing plant protection products.	X	
	There are facilities to deal with spillage to avoid contamination of the ground water.	X	
	The product inventory is documented and readily available.		X
	All plant protection products are stored in their original package.	X	
	Liquids are not stored on shelves above powders.		X
	Obsolete plant protection products are securely maintained and identified and disposed off by authorized or approved channels.		X
Empty Plant Protection	The re-use of empty plant protection product containers for purposes other than containing and transporting of the identical product is avoided.		X
	The disposal of empty plant protection product containers does occur in a manner that avoids exposure to humans and the environment.		X
	Official collection and disposal systems are used when available.		X
	Empty containers are rinsed either via the use of an integrated	X	

Product Containers and Waste Disposal	pressure rinsing device on the application equipment, or at least three times with water. The rinsate from empty containers is returned to the application equipment tank. Local regulations regarding disposal or destruction of containers are followed.		
	The premises have adequate provisions for waste disposal.		X
	There is a farm waste management plan. Waste recycling avoids or reduces wastage and avoids the use of landfill or burning.		X

PRINCIPLE 3: Safe working conditions through training and education, use of protective clothing and proper and timely assistance in the event of accidents

Safe Working conditions	The farm has a health, safety and hygiene policy and procedures including issues of the risk assessment.		X
	First Aid kits are present at all permanent sites and in the vicinity of fieldwork.		X
	Workers (including subcontractors) are equipped with suitable protective clothing in accordance with legal requirements and/or label instructions or as authorized by a competent authority. Protective clothing is cleaned after use and stored so as to prevent contamination of clothing or equipment.	X	
	Potential hazards are clearly identified by warning signs and placed where appropriate.		X
	There are records kept for training activities and attendees.		X
	All workers handling and/or administering chemicals, disinfectants, plant protection products, biocides or other hazardous substances and all workers operating dangerous or complex equipment as defined in the risk assessment have certificates of competence, and/or details of other such qualifications.	X	
	All workers received adequate health and safety training and they are instructed according to the risk assessment.		X
	Workers have access to clean food storage areas, designated dining areas, hand washing facilities and drinking water.		X
	On site living quarters are habitable and have the basic services and facilities.		X
Plant Protection Product Handling	The accident procedure is evident within ten meters of the plant protection product/ chemical storage facilities.		X
	There are facilities to deal with accidental operator contamination.		X
	There are procedures dealing with re-entry times on the farm.	X	

PRINCIPLE 4: Biomass production shall not violate human rights, labor rights or land rights. It shall promote responsible labor conditions and workers' health, safety and welfare and shall be based on responsible community relations.

The criteria listed here is based on internationally recognized requirements concerning

social aspects			
	A self-declaration on good social practice regarding human rights has been communicated to the employees and signed by the farm management and the employees' representative.		X
	Employment conditions comply with equality principles.	X	
	There is no indication of discrimination (distinction, exclusion or preference) practiced that denies or impairs equality of opportunity, conditions or treatment based on individual characteristics and group membership or association. For example, on the basis of: race, caste, nationality, religion, disability, gender etc.	X	
	There is no indication of forced labor at the farm.	X	
	Workers have the freedom to join labor organizations or organize themselves to perform collective bargaining. Workers must have the right to organize and negotiate their working conditions. Workers exercising this right should not be discriminated against or suffer repercussions.	X	
	The farm does pay a living wage which meets at least legal or industry minimum standards.	X	
	The person responsible for workers' health, safety and good social practice and the elected individual(s) of trust have knowledge about and/or access to recent national labor regulations/collective bargaining agreements.		X
	All impacts for surrounding areas, communities, users and land owners taken into account and sufficiently compensated for.		X
	The management does hold regular two-way communication meetings with their employees where issues affecting the business or related to worker health, safety and welfare can be discussed openly.		X
	There is at least one worker or a workers' council elected freely and democratically who represent the interests of the staff to the management.		X
	There is a complaint form and/or procedure available on the farm, where employees and affected communities can make a complaint.		X
	All children living on the farm have access to quality primary school education.	X	
	There are records that provide an accurate overview of all employees (including seasonal workers and subcontracted workers on the farm) and indicate full names, a job description, date of birth, date of entry, wage and the period of employment.		X
	No minors are employed on the farm.	X	

	All employees are provided with fair legal contracts. Copies of working contracts can be shown for every employee indicated in the records. These have been signed by both the employee and the employer.		X
	There is a time recording system that shows daily working time and overtime on a daily basis for all employees.		X
	The working hours and breaks of the individual worker are indicated in the time records comply with legal regulations and/or collective bargaining agreements.		X
	Pay slips document the conformity of payment with at least legal regulations and/or collective bargaining agreements.		X
	Other forms of social benefits are offered by the employer to employees, their families and/or community.		X
	Mediation is available in case of a social conflict.		X
	Fair and transparent contract farming arrangements are in place.		X
	Biomass production does not impair food security.		X

PRINCIPLE 5: Biomass production shall take place in compliance with all applicable regional and national laws and shall follow relevant international treaties

	The producer can proof that the land is used legitimately and that traditional land rights have been secured.	X	
	There is awareness of, and compliance with, all applicable regional and national laws and ratified international treaties.	X	

PRINCIPLE 6: Good management practices shall be implemented

	A recording system is established for each unit of production. These records must be kept in an ordered and up-to-date condition for at least 3 years.	X	
	Records are kept for the description of the areas in use.	X	
	In case of the engagement of subcontractors they must comply fully with the ISCC standard and provide the respective documentation and information.	X	

(Source:http://www.iscc-system.org/uploads/media/ISCC_EU_202_Sustainability_Requirements-Requirements_for_theProduction_of_Biomasse_2.3_01.pdf. M1 Major Must, M2 Minor Must, HCV high conservation value, EIA environmental impact assessment, IPM integrated pest management, PPP plant protection products.)

3 The practice of bioenergy development in China – Evidence from Jiangsu province[1]

3.1 Introduction

The use of biomass to produce bioenergy and biomaterials as substitutes for goods based on petro-chemicals is a response to several global problems. Biomass-based products can match a wide range of energy demands. They are renewable and can be stored at relatively moderate losses compared to other forms of renewable energy. The global supply of bioenergy has doubled in the past forty years. In 2010, the global supply of bioenergy reached 1277 Million tonnes of oil equivalent (Mtoe), ranking fourth after the main traditional fossil fuels [crude oil (4069 Mtoe), coal (3596 Mtoe) and natural gas (2719 Mtoe)] but leading the contribution of renewable energy types (International Energy Agency, 2012).

While receiving worldwide attention, there are still notable differences in the development of bioenergy between highly developed and least developed countries. These differences include the following four aspects:

(1) Differences in the share of bioenergy in the energy source mix

While the total contribution of modern bioenergy in highly developed countries is on average only about 3% of total primary energy supply, bioenergy contributes some 22% in developing countries' total primary energy mix, and values as high as 80% for some of the least developed countries (Chum et al., 2011, Koljonen et al., 2013).

(2) Differences in bioenergy utilization forms

Owing to the economic feasibility and adoption of modern conversion processes, biomass in developed countries is transformed to a higher degree into commercial energy forms, such as electricity, biodiesel, and ethanol, and thus can be introduced into existing energy markets (Demirbas and Demirbas, 2007, Plieninger, Bens, 2006). In contrast, in the rural areas of least

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[1] The adaptation of this chapter has been submitted to the journal "Energy for Sustainable Development".

developed countries, biomass is still being utilized in the traditional way, for example, by being burned in rural areas as a direct heat source used for heating and cooking.

(3) Differences in motivation for development

The concept of modern bioenergy was conceived in developed countries in the context of mitigating problems, such as climate change, energy shortage, and local air pollution. On the other hand, least developed countries place high hopes on the role of bioenergy in boosting social and economic development (Domac, Richards, 2005). The use of biomass there is expected to bring local farmers some income and even to create a new branch of industry, also called the sunrise industry, aiming at driving these countries towards industrialization (Silveira, 2005).

(4) Differences in socio-economic conditions

Continued population growth in least developed countries increases the competition for limited natural resources, such as land and water. The lack of ability to mitigate or adapt to the consequences of climate change could exacerbate this competition in the future, thereby raising the propensity for conflicts in these areas. The possibility of such conflicts makes the introduction of energy crops in these countries a highly sensitive matter facing a number of challenges (Scheffran, 2009, Schneider and McCarl, 2003). Moreover, the agriculture sector in those countries, compared with other sectors, is less attractive for the investors, which implies insufficient funding for implementation of bioenergy. Besides, small-scale and vastly scattered farmers and a less developed infrastructure lead to a distinct environment for the development of bioenergy in these countries.

In view of the differences, it is likely that the bioenergy development in highly developed and least developed countries performs in different ways. Correspondingly, existing research on this aspect has, in most cases, been conducted in one single group. This research method can facilitate the generalization of common features within each type of the countries, but it is far less enough to fully demonstrate the dynamic evolutionary process of bioenergy utilization.

China, as the biggest emerging economy in the world, has concurrently the characteristics of both developed and developing countries. It accommodates the largest population while practicing a transitional process of biomass utilization on its soil. By exploring the concrete development experience in depth from one representative area, we can, on the one hand, diversify the empirical studies of bioenergy development from the perspective of an emerging economy, and, on the other hand, vividly delineate this evolutionary process occurring in China.

The chapter is organized as follows. First, an overview of the characteristic features of the case region is provided. Next, after analyzing the local biomass potential and its utilization pathways, a suitable mode of bioenergy industry construction is presented. Specifically, the structure of both supply side and demand side is considered. Finally, we will generalize the advantages and disadvantages of alternative pathways of bioenergy development in a bid to provide some guidelines for other areas of China.

3.2 Regional review

The Jiangsu Province lies on the eastern coast of China and contains 13 cities. Together with the city of Shanghai and the Zhejiang Province, it constitutes the most advanced economic area in China, also referred to as the Yangtze River Delta Economic Circle (YRDEC) (Figure 3-1).

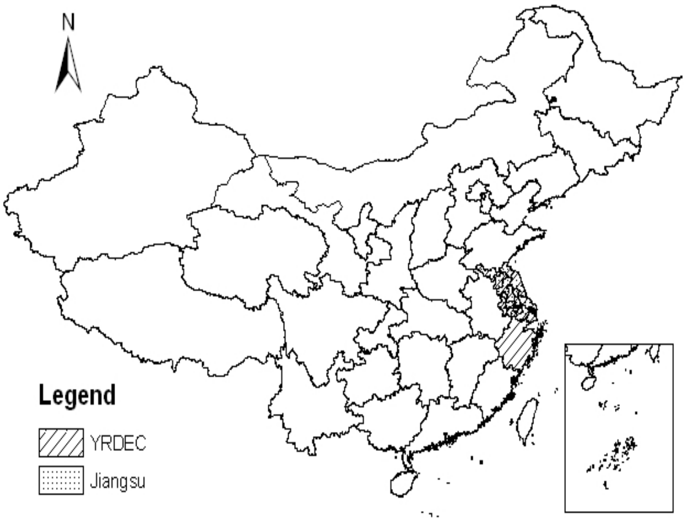


Figure 3-1 The location of Jiangsu province

Due to differences in topography and socio-economic development, the Jiangsu Province is often divided into southern, central, and northern sub-regions. While, as a whole, the Jiangsu Province belongs to the most developed regions in China, there is still a large regional disparity between these three parts. Specifically, the combined share of secondary (manufacturing) and tertiary (service) industries in the southern sub-region is relatively high and is one reason for the higher average income and better living conditions compared to the central and northern sub-region. Due to its favorable climatic and topographic conditions, the primary industry is considered to be the pillar of the northern sub-region. The agricultural suitability in the north made the Jiangsu province one of the major grain and cotton production bases in China for more than one thousand years. In addition to regional differences, a dual economy has also existed for a long time in the entire Jiangsu Province, resulting in an enormous gap between urban centers and rural areas. For example, in 2009 the average per-capita income of urban and rural households amounted to 20,552 CNY and 8,004 CNY, respectively (Statistic Bureau of Jiangsu Province, 2010). The general socio-economic differences between the three sub-regions of the Jiangsu Province are presented in Table 3-1.

Table 3-1 Socio-economic indicators in Jiangsu province

Sub-region	Population (10^6)	GDP per capita (CNY)	GDP by industry (10^9CNY)			Arable area (10^3 ha)	GHGs emission (10^6 t)
			Primary	Secondary	Tertiary		
Southern	30.80	69278	53.24	1171.70	890.48	934.06	102.00
Central	16.30	39263	51.51	359.26	228.25	1080.66	31.72
Northern	30.15	23835	106.53	353.27	259.88	2674.76	28.59

Data source: (Li et al., 2008, Statistic Bureau of Jiangsu Province, 2010)

In recent times, rapid economic growth has caused a sharp rise in the consumption of energy in the Jiangsu Province. By the end of 2012, the provincial total energy consumption was 288 million tonnes of coal equivalent (Mtce) (Statistic Bureau of Jiangsu Province, 2013). Furthermore, it is estimated to reach 584 Mtce by 2020, more than doubling the current level (Wang et al., 2009). While consuming a large amount of energy, energy resources in the

Jiangsu Province are scarce. Its exploitable oil and coal reserves account only for 0.2% and 1.2%, respectively, of China's reserves. More than 92% of coal, 93% of crude oil and 99% of natural gas were imported from other provinces, neighboring countries, or even from overseas (People's Government of Jiangsu Province, 2012a). High dependence on international fossil fuel markets makes a country vulnerable to international price fluctuations. In this context, increasing energy security through domestic and renewable resources becomes a priority issue for the sustainable development process of the Jiangsu Province.

High levels of fossil fuel consumption also expose the region to severe air pollution and increase GHGs emissions. In a statistical analysis of the provincial inventory of greenhouse gas emissions in 1990 based on the methods provided in the IPCC Guidelines (1995), Xu et al. (1999) demonstrate that energy consumption is the main source of CO_2 emissions in the Jiangsu Province, and account for up to 91.6% of total emissions. Meanwhile, the government of the Jiangsu Province has issued the "Comprehensive Activity Plan for Energy-Saving and GHGs Emission Reduction of Jiangsu Province in 2011-2015" (People's government of Jiangsu province, 2012b). This plan mandates that the energy consumption per unit GDP (104 CNY) in the Jiangsu province should decrease to 0.602 tonnes of standard coal equivalent (SCE) by 2015. The 18% reduction, compared to 2010 levels, implies a CO2 emission reduction between 2011 and 2015 of about 42 million tonnes.

To cope with the above issues of energy security, air pollution reduction, and GHGs emission mitigation, the participation of renewable energy in the local energy source mix has been emphasized in the 12th Five-year Energy Development Plan in the Jiangsu Province. Although it is only a supplement to fossil fuels in terms of its share in energy supply (In 2015, it is to account for 5.08% of the provincial primary energy consumption), renewable energy is expected to reform the local energy industry (People's Government of Jiangsu Province, 2012a). In Table 3-2, we show the main sources of the renewable energy and their utilization potentials for power generation in the Jiangsu province.

Table 3-2 The main sources of renewable energies for power generation in Jiangsu province

Potential and use Renewable energy source	Exploitable potential (GW) [1]	Installed capacity in 2010 (GW)	Projected installed capacity in 2015 (GW) [2]	Demonstrative cost (CNY/kwh)
Wind onshore	19.08	1.37[2]	2.40	0.632[4]
Wind offshore	22.09	0.00[2]	3.60	0.965[5]
Solar PV	4.71-10.85	0.003[3]	0.80	1.260[6]
Rural biomass	24.58	0.80[3]	1.00	0.834[7]
Municipal waste and sludge	0.92	0.80[3]	-	0.587[8]

Notes: 1) The values of exploitable potential are calculated in the assumption that annual utilization hours of installed turbine are 7650 hours; 2) Data source: 1. (Hong et al., 2013); 2. (People's Government of Jiangsu Province, 2012a); 3. (Zhou and Zhang, 2010); 4. (Wang and Lu, 2009); 5. (Yang et al., 2010); 6. (Ma et al., 2010); 7. (Li and Hu, 2009); 8. (Yang and Ma, 2006)

In terms of power generation, the currently installed capacity of biomass in the Jiangsu province ranks first among alternative renewable energy types, although the demonstrative production cost of power derived from biomass is not the cheapest. Together with wind energy and solar energy, bioenergy is an indispensable sector of energy supply in the Jiangsu province.

As mentioned earlier, agriculture plays an important role in the Jiangsu Province, especially in its central and northern sub-region. In 2012, the grain output of Jiangsu province increased to 33.73 million tonnes, which is higher than the total output of its four neighboring administrative regions – the three coastal provinces of Guangdong, Fujian, Zhejiang and the city of Shanghai. In fact, the grain output in 2012 ranked fourth in entire China. The high yield of grains is accompanied by the high yield of crop biomass. An abundant supply of straw provides a stable feedstock for the bioenergy industry. The diverse utilization channels of straw can create additional business opportunities and increase the income of farmers. Higher incomes will ultimately improve the quality of life in rural areas. Li et al. (2008) estimate that as many as 10,000 companies in the Jiangsu province could be established for gathering, processing, transportation, and selling of biomass. This estimate is based on the assumption that each village installs a small pelletizing plant with an annual output of 3,000t. Collectively, such companies could generate annual revenue of 9-14 billion CNY and support about 300,000 additional jobs. The sale of straw to the biorefineries could create an additional income of 6 billion CNY to farmers. More importantly, the modern bioenergy utilization opens a window for the vast rural areas in the Jiangsu Province by linking conventional agriculture to a modernized energy supply system. In other words, it would be an opportunity for the Jiangsu Province to attract investments and stimulate the socio-economic development in rural areas. This could be helpful for eliminating the regional disparity and the gap between urban and rural areas, which is the goal that the Chinese authorities are pursuing with the “new village construction” campaign.

There is yet another feature of the Jiangsu province that should be mentioned here. Certain coastal areas, in particular some counties within the administrative regions of Lianyungang, Yancheng and Nantong, have mudflats covering more than 6,000 km2 (Ling, 2010). This land resource could be used for large-scale biomass plantations. In summary, the Jiangsu Province is an attractive region for bioenergy development both in terms of demand and supply conditions (Figure 3-2).

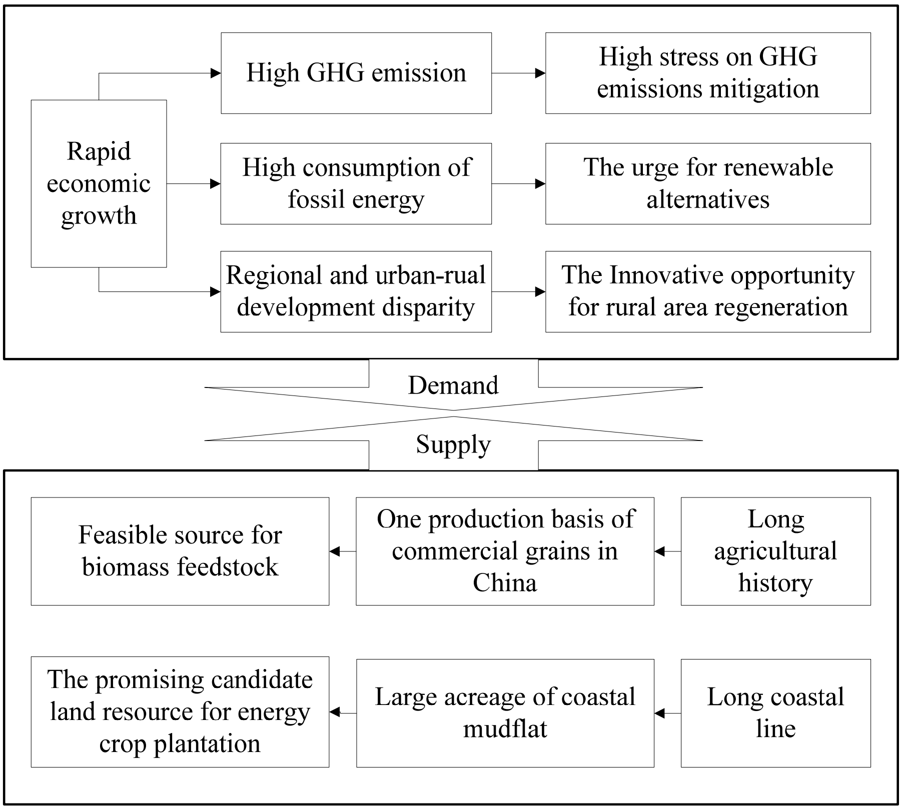


Figure 3-2 Conditions for demand and supply of bioenergy in Jiangsu province

3.3 The current local practice of bioenergy development

The organization of bioenergy production can be roughly divided into four types: (1) centralized biomass plantation and energy production; (2) distributed biomass plantation and energy generation; (3) centralized biomass plantation and distributed energy production, and (4) distributed biomass plantation and centralized energy production. For most developing countries, the local conditions of current agricultural systems, specifically the existence of small-scale peasant farmers, favors the option of distributed biomass plantations. While distributed plantations would increase the biomass collection cost compared to centralized ones, there are benefits from 1) maintaining a higher degree of biodiversity with diffuse plantations of energy crops on a small-scale and 2) preventing some of the peasants from being excluded or marginalized due to centralization. As to the energy production, we argue that large centralized production can facilitate the biomass conversion and attract investment in auxiliary industry, creating industrial chains which strengthen the entire bioenergy industry.

3.3.1 The rural biomass potential

By comparing the resource potential and utilization directions of both urban sewage and rural biomass, the government has posed high expectations on the latter in its "12th Five-year Energy Development Plan" According to the assessment of local resources, the available rural biomass in the Jiangsu Province was estimated at 41.5 Mtoe in 2006 and 54 Mtoe in 2010, with the expected potential to reach 61 Mtoe in 2015. The two main sources of rural biomass are crop straw and manure from humans and livestock (Table 3-3).

Table 3-3 The biomass potential in Jiangsu rural area

Items	Quantity available (million tonnes)			Proportion (%)		
Year	2006	2010	2015	2006	2010	2015
Crop straw	19.88	22.50	24.00	48.01	41.82	39.36
Forest biomass resource	2.97	10.72	14.25	7.17	19.93	23.37
Manure from humans and livestock	18.56	20.35	22.35	44.82	37.83	36.66
Energy crops (for biodiesel)	0	0.23	0.37	0	0.42	0.61
Total	41.41	53.80	60.97	100	100	100

Data source: (Zhang et al., 2008)

Manure is most suitable as a feedstock for biogas production. Due to its dispersed distribution of small farms and the difficulties associated with large-scale collection and long distance transportation, to date such manure is mainly fermented in methane tanks with a volume of about 3 m3. In the vast rural areas of the Jiangsu Province, this type of biogas is primarily used to meet the needs of heat for cooking and light. Its intrinsic characteristics imply that manure is only suitable for distributed energy production, but little adaptable for large-scale centralized energy production, such as commercial production of electricity or liquid fuels. By contrast, crop straw has a much wider range of possible applications than manure, because it can be more cost-effectively transformed into electricity, bioethanol or biodiesel. The process of centralized combustion or biochemical-conversion can be commercialized and integrated into the current energy supply system. Therefore, in the remainder of this paper, we will focus on the utilization of crop straw.

3.3.2 The current situation of crop straw utilization

It is estimated that the total amount of crop straw in the Jiangsu Province averages around 40 million tonnes per year. The southern, central and northern sub-regions contribute 15.1%, 27.2% and 57.7%, respectively. There are five utilization pathways which are demonstrated in Figure 3-3. The letters "Nor.", "Cen." and "Sou." stand for the three sub-regions.

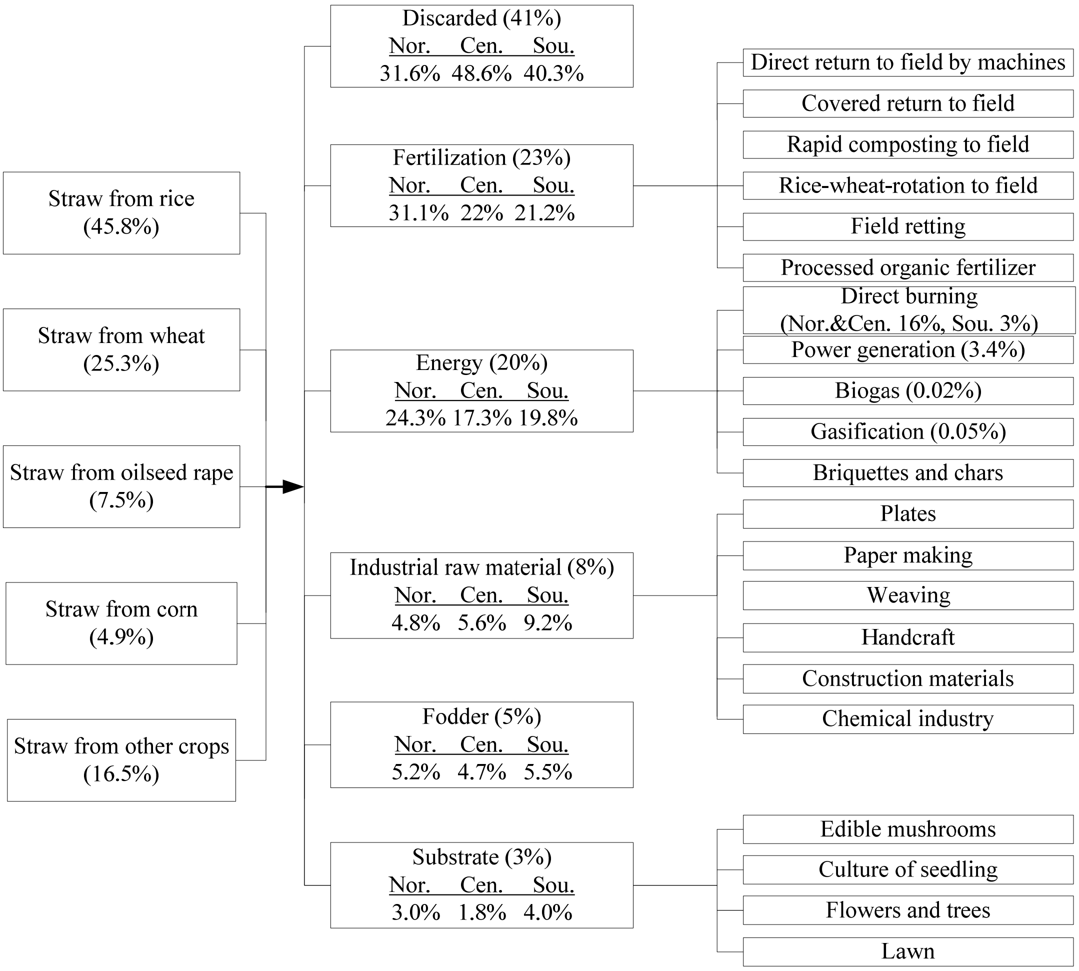


Figure 3-3 The source and utilization of crop straw in Jiangsu province in 2008

Date source: (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010)

In the past decade, the Jiangsu Province exploited the energy potential of crop straw in four product types: power, liquid fuel, gas fuel, and solid fuel. Among those four alternatives, power generation via briquettes is the currently most advanced method.

By the end of 2012, 30 demonstration projects of biomass-based power plants with 0.803 GW installed capacity had been approved in the Jiangsu Province, of which 13 had already been connected to the electricity grid. Most of these plants employ the direct combustion technology and are located in the northern and central sub-regions, consuming 3.6 million tonnes of crop straw (Yan, 2013). This value is projected to rise to 6 million tonnes by 2015 (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010).

In addition to power generation, the option of liquid biofuel production, e.g. bioethanol, is in the stage of demonstration in the Jiangsu province. In 2006, gasoline containing 10 percent bioethanol (E10) was introduced in the northern sub-region. Currently, the bioethanol originates from the 1st generation process, the fermentation of grains from corn and sorghum. In the aim of reducing adverse impacts on food supply, 2nd generation type biofuels, e.g. bioethanol fermented from cellulosic crop straw, is being developed in the Jiangsu province. In 2010, a new demonstration plant was built in the city of Huai'an, which is capable of fermenting 13,000 tonnes of crop straw per year (Xiong, 2010). It is expected that, in the near future, the biomass-based bioethanol can be widely used for the E10 gasoline production.

In terms of gas fuel, biogas has a relatively longer history than other utilization paths. By the end of 2008, more than 10,000 households were using about 10,000 tonnes of crop straw to ferment biogas. In addition, 72 gasification stations with each offering gas to 300 households have been installed in the Jiangsu province in the context of the “new village construction” campaign. Regarding solid fuel options, briquettes for power generation at processing cost of 85 CNY/t (Qi, 2007) may be used at small scales. The utilization of other methods is rather small (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010). In Table 3-4, the cost structures of those different forms of bioenergy in the Jiangsu Province are displayed.

Although the Jiangsu Province has made great progress over the last years in the field of modern bioenergy utilization, the total utilization of crop straws remains below 60%. This is

Table 3-4 The cost structures of three main forms of bioenergy in Jiangsu Province

Cost structure	Annualized fixed cost	Feedstock cost	Operational cost	Total	Data source
Type of bioenergy	10^3CNY/t 10^3CNY/MW CNY/m^3	CNY/t CNY/kWh CNY/m^3	10^3CNY/ t 10^3CNY/MW CNY/m^3	CNY/t CNY/kWh CNY/m^3	
Biofuel	0.249	6160	1.461	7870	Jiang et al., 2012b
Bioelectricity[1]	713	0.459	383.360	0.6022	Zhang et al., 2012
Biogas	0.131	0.030	0.050	0.211	Gu and Zhou, 1999

Notes: 1. The preliminary cost data of bioelectricity production is from an internal report on a "Biomass power plant forum" which organized by Jiangsu Electric Power Industry Association in February, 2012.

2. The unit cost of power generation is calculated in the assumption that annual utilization hours of installed turbine are 7650 hours. In reality, due to the unstable supply of biomass feedstock and equipment maintenance, the utilization hours are hardly to be reached. In this case, the unit cost in reality should be higher than the 0.6 CNY/kwh and usually fluctuates around 0.8 CNY/kWh (see Table 3-2).

clearer for only considering the utilization ratio of crop straw for commercialized energy production (see Fig. 3). For example, as little as 3.4 % of crop straw is used for power generation, while the percentage of crop straw for the production of bioethanol or biodiesel is practically negligible. Meanwhile, as much as 16.4 million tonnes of crop straw have been discarded and burned off resulting in severe air pollution during the harvest season and the loss of soil fertility. By leading the discarded crop straw into modern bioenergy use, we can benefit a lot in both bioenergy industry and local infrastructure. Therefore, it can be concluded that the use of crop straw for centralized energy generation in the Jiangsu Province has a promising future. Meanwhile, we need to notice that the boosting demand of crop straw for bioenergy use could make its use for other purposes more expensive, and as such a comprehensive and deliberate consideration of crop straw utilization is necessary.

3.4 The construction of a bioenergy industry in the Jiangsu province

The local strategy of bioenergy development in the Jiangsu province focuses on large-scale centralized production of energy (power, liquid fuel, gas fuel, and solid fuel) from decentralized biomass (crop straw or energy crops). During this process, certain economic, social and environmental requirements have to be met (Scheffran, 2009).

3.4.1 Stakeholder analysis

The understanding of the stakeholder concept has changed considerably in the past decades. In general, there is a twofold definition of stakeholders. In the narrow sense, the term may be defined as “any identifiable group or individual on whom the organization is dependent for its continued survival” (Freeman and Reed, 1983). A more generalized definition considers a stakeholder to be “any identifiable group or individual who can affect the achievement of an organization’s objects or who is affected by the achievement of an organization’s objectives” (Freeman and Reed, 1983). Mitchell et al. (1997) propose that the typology of stakeholders should be based on the stakeholders’ possession or non-possession of (1) power to impact the organization, (2) legitimacy of their relationship towards the organization, and (3) urgency of their claims, i.e. the degree to which stakeholders' claims can draw attentions of organization's managers. In accordance with the above idea, two layers of stakeholders in the bioenergy industry in the Jiangsu Province can be defined: The fundamental layer refers to “central stakeholders”, who fall under the narrow definition. The actors in this layer form the bioenergy “organization”, i.e. the supply chain of bioenergy. It is their actions that determine the success or failure of the bioenergy industry. The secondary layer of actors who fall under the broad definition are “peripheral stakeholders” who are outside or at the margin of the supply chain. They are immediately affected by the process of bioenergy production, but in turn they also exert their own positive or negative influence on the supply chain.

We use life cycle analysis (LCA) to include in our assessment all major actors of the bioenergy industry in the Jiangsu Province. The complete life cycle of biomass comprises five phases: cultivation, harvesting, processing, distribution and utilization (Scheffran, 2009). Of these phases, the first four involve the supply of bioenergy products to the bioenergy market, whereas the last phase involves the consumption of the final product by the end user. Actors that actively take part in the supply chain are defined as central stakeholders within the framework of our analysis. Specifically, this group includes farmers, haulers, and bioenergy plant operators. By analogy, actors that are involved in the last, consumptive phase are referred to as peripheral stakeholders, such as the consumers of bioenergy products and other actors defined as peripheral by Mitchell et al. (1997). In our research, these include governments (central, provincial, and local governments), non-governmental organizations and research institutes, local residents and communities, bioenergy end-users and the general public. They influence the general operating environment for central stakeholders through a risk-and-benefit-sharing mechanism. The detailed material and information linkages among the stakeholders are presented in Figure 3-4.

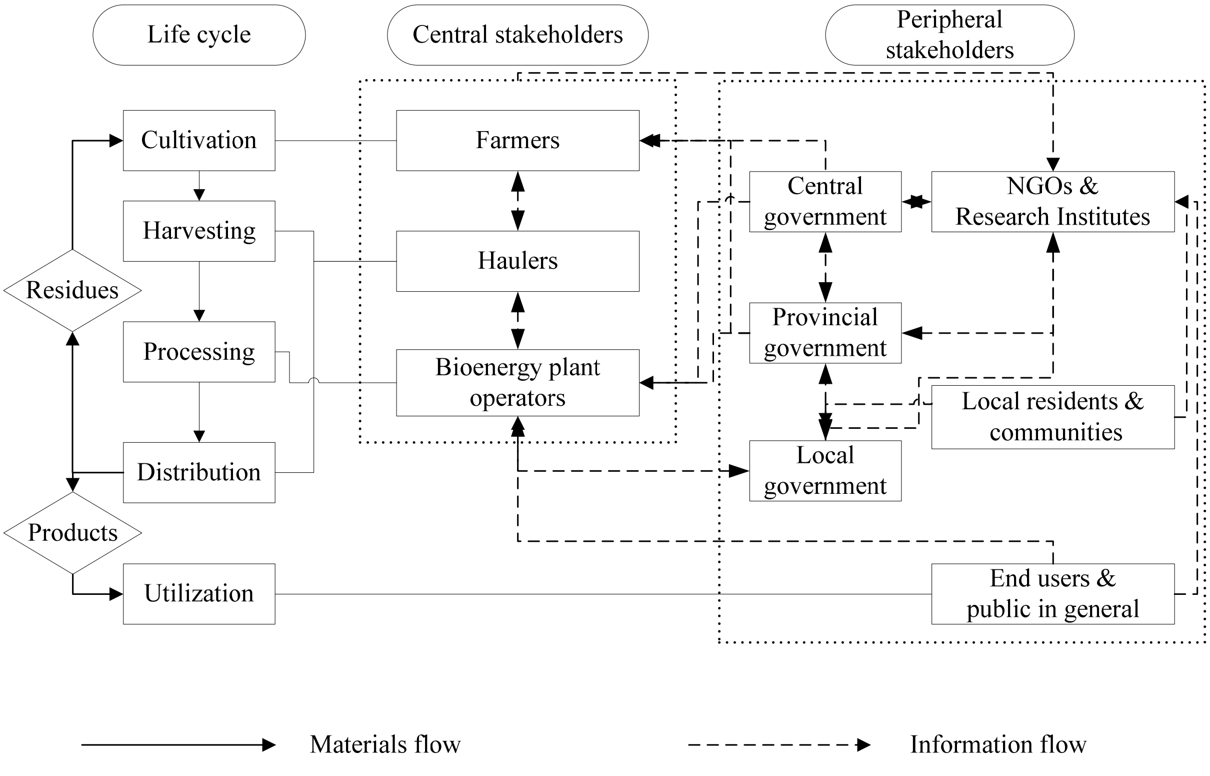


Figure 3-4 Central and peripheral stakeholders in the bioenergy industry

3.4.2 Supply side construction: The management of the bioenergy supply chain

According to Mentzer et al. (2001), a supply chain is generally defined as “a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer”. In the case of the bioenergy industry, farmers form the upstream segment. They are in control of a steady and adequate feedstock supply for the subsequent bioenergy production. As independent agents, they decide which agricultural crops to plant on how much land and under which method of cultivation. Their decision-making process is repeated on an annual basis, and as such is relatively flexible and able to adjust to changing economic condition quickly. These conditions include expected net benefits of particular crop management systems and their perceived risk levels. Once perennial energy crops are introduced, the annual mode of decision making cannot be sustained. The deviation from the established annual cultivation method (re-distribution of capital, uncertainties of long-term financial rewards, reduced adaptability) obstructs the process of introducing energy crops.

Further downstream in the supply chain are the bioenergy plant operators who have a central position in the whole bioenergy industry. Viewed upstream, these operators purchase biomass feedstock from farmers and provide them with income in return. Viewed downstream, they compete with other commercial forms of energy supply. In addition, they also communicate with peripheral stakeholders. The success of energy crop introduction to the Jiangsu Province mainly depends on the efficiency of the adopted technology, which is affected by the technical feasibility and the economic conditions for investing in these technologies including supporting policies.

Haulers are the carriers of material flow. They transport feedstock from farmers to the processing plants and distribute biofuel products from processing plants to end users. They also transport processing waste, e.g. bioslurry, back to the farms. Due to certain intrinsic characteristics of biomass, i.e. low bulk density and seasonal availability, flexible and affordable transportation services are crucial for the sustainable development of the bioenergy industry. In the case of the Jiangsu Province, these actors usually include bioenergy plant operators and professionalized peasant farmers' agents.

Mentzer et al.(2001) view supply chain management (SCM) as “the system, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across business within the supply chain, for the purpose of improving the long-term performance of the individual companies and the supply chain as a whole.” Moreover, Gold (2011) underlines five pivotal elements for the evaluation of supply chain design and management. These elements are (1) supply chain cooperation, (2) supply chain coordination, (3) supply chain governance, (4) long-term relationships and (5) communication for conflict settlement and joint development.

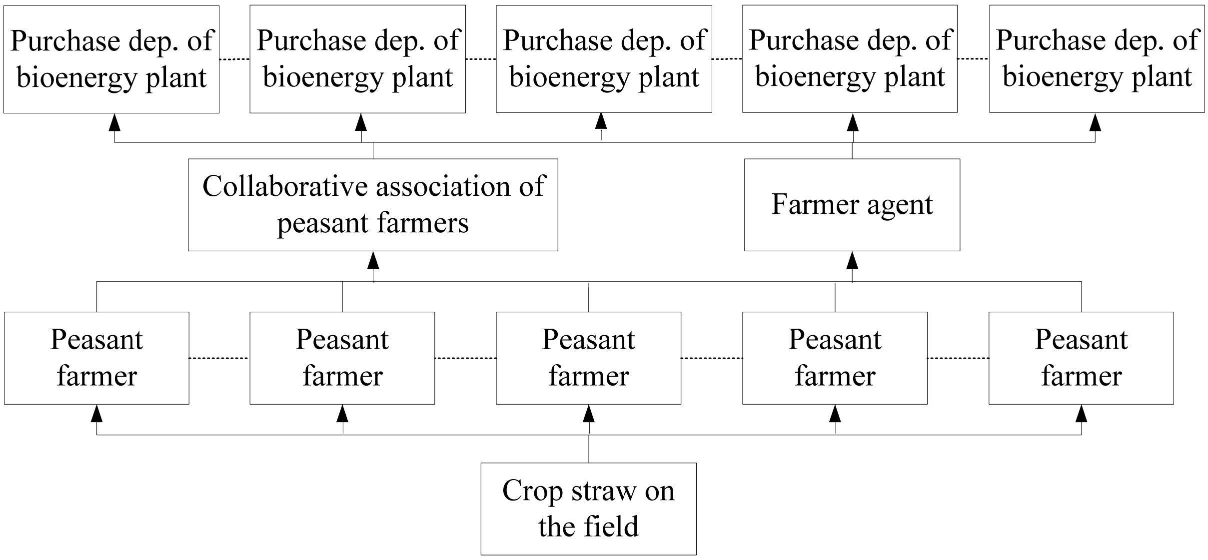
In the case of the Jiangsu Province, the government has proposed its own mode of supply chain management which conforms to the above guidelines. It has integrated the construction of the bioenergy supply chain into its agricultural reformation process. This is marked by the introduction of "energy-oriented agriculture". In order to mitigate the cost of this transition process, the agricultural reform is setup as a gradual development in two phases: 1) utilization of crop straw and 2) utilization of perennial energy crops.

3.4.2.1 Phase1: Utilization of Crop Straw

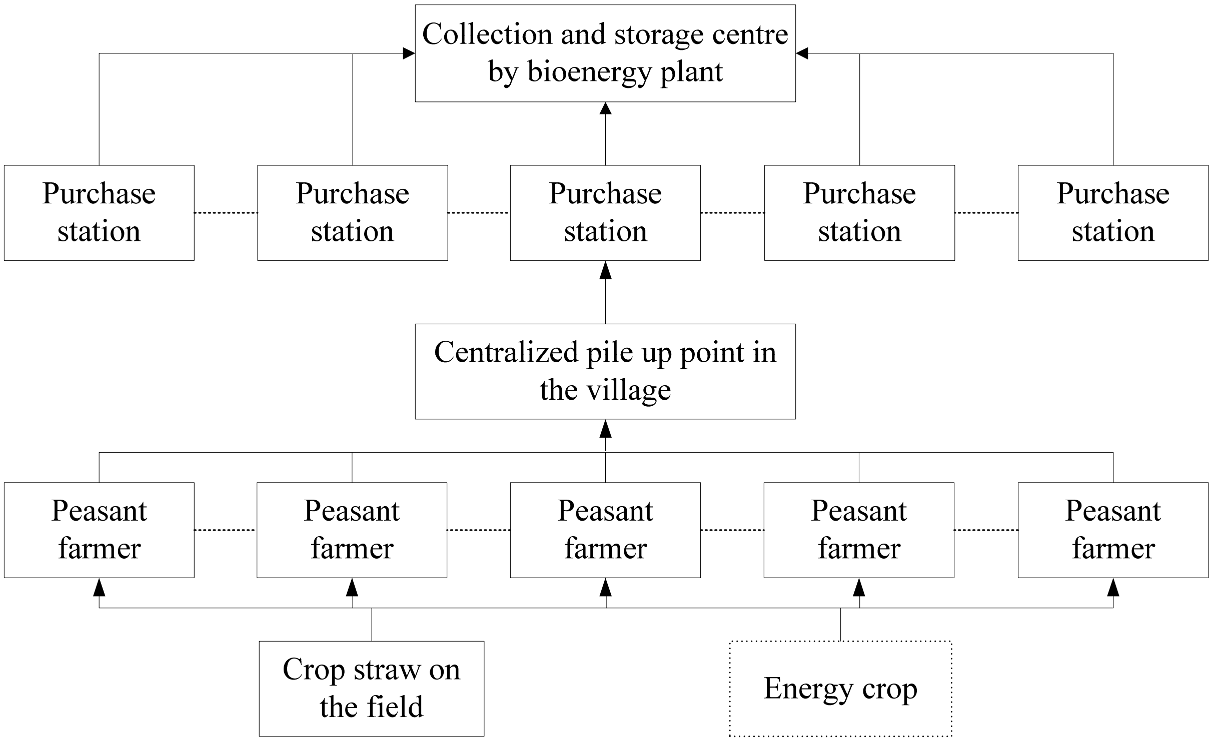
For developing countries, the efficient exploitation of existing crop straw presents a considerable potential for developing bioenergy without unduly disrupting existing agricultural practices and food production or requiring new land entering into production. Furthermore, it could become an additional source of revenue for farmers. Since continued removal of straw and other crop residues could endanger long-term soil quality, the losing fertility could be compensated through the return of processing by-products such as bioslurry to the fields (Wei et al., 2011). However, the incurred transportation cost of bioslurry has to be simultaneously taken into consideration so as to avoid unprofitable investments. Considering the potential supply of crop straw and the overall demand for biomass in the Jiangsu Province, this residue type could become the main bioenergy feedstock in the next decade.

The change of farming systems, which have evolved over thousand years, may require a substantial transitional period. During this period farmers can adjust to an “energy-oriented agriculture", both in a technological and psychological sense. Thus, introducing the crop's energy value as additional commodity to the traditional agricultural food production system needs to be accepted by the farmers. This period can be thought of as phase 1 of the agricultural reform, or as the construction phase for a bioenergy industry supply chain.

Current agriculture in the Jiangsu Province still consists of many small-scale peasants. Such farming is also typical of most other developing countries. The peasant farmers, who individually own small pieces of land, are scattered and often far away from relevant commodity markets. Individual farmers are price-takers, who do not have market power and do not directly influence the direction of agricultural development on an individual basis. Therefore, the professional associations of farmers and peasant farmers' agents (farmers' representatives), who have gradually emerged with the fast increasing demand of crop straw, and who rely on the collective power of individual peasant farmers as well as large-scale bioenergy plants (plants' representatives), are capable of taking on such responsibility. Distinguished by the different roles of both representatives in the crop straw collection process, two management methods of the bioenergy supply chain in the Jiangsu Province are being shaped ("one to multiple" and "multiple to multiple"), which are illustrated in Figure 3-5.



Pattern 1: Multiple to multiple



Pattern 2: One to Multiple

Figure 3-5 Two patterns of bioenergy supply chain management

Pattern 1 "Multiple to Multiple" means that many bioenergy plants are facing many peasant farmers. In this pattern, the actors both on the supply and the demand side of the biomass market are not strong enough to control others, and therefore face normal competition. As bioenergy plants do not have enough resources to deal with thousands of individual peasant farmers, the collaborative associations of peasant farmers and professional peasant farmers' agents can facilitate the negotiation process and help in the exchange of information between biomass suppliers and consumers. However, there are also negative side effects to pattern 1. First, in very competitive markets, the price of biomass is usually subject to larger fluctuations. The uncertainty about future prices will create an economic risk on both the biomass supply and demand side. Second, because of the competition for crop straw between the bioenergy users and other traditional straw users (i.e. paper and sheets producers), farm associations are eager to sell straw to the customer who offers the highest price. The loose internal structure of straw suppliers primarily restricts their focus to tangible benefits in the short run, preventing them from negotiating long-term contracts with bioenergy plants.

Pattern 2 "One to Multiple", by contrast, refers to one or few large bioenergy plants facing many peasant farmers. These few plants will then have substantial power to influence the biomass market. In such a situation, the bioenergy plants are likely to build up an exclusive collection and storage base with a radius of 50-80 km and establish several purchasing stations, each covering an area of 2-5 km in radius (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010). Such infrastructure makes it attractive for the plant operators to sign long-term purchase contracts with peasant farmers. From the farmers' perspective, such arrangements can guarantee long-run economic benefits and reduce uncertainties of competitive markets. From the plant owners' perspective, such contracts secure a stable supply of biomass feedstock at a relatively low price. Especially, by stipulating the types and quality of biomass in the contract, bioenergy plants can gradually introduce energy crops and lead the peasant farmers to switch to an energy-oriented agriculture without explicitly changing any relationships in the established supply chain. Due to such benefits, this pattern seems more suitable for bioenergy development in the Jiangsu Province.

3.4.2.2 Phase 2: Utilization of perennial energy crops

Along with the development of the bioenergy industry, steadily increased demand for biomass feedstock is anticipated. Once the existing crop straw cannot fully meet the need, the introduction of perennial energy crops to the Jiangsu Province could be one of the available alternatives. The introduction of new crops is a major development and could be characterized as phase 2 of the construction of the bioenergy supply chain.

- The selection of energy crops

For developing countries, the choice of dedicated energy crop species is not a simple matter. A number of non-technical factors must be taken into consideration, including food security, environmental protection, social equity and national/rural development. In order to assure the success of such decisions, this choice must be informed by market options at local, national and international scales.

With the support of national and provincial policies, in recent years, a number of research institutes have begun to search for suitable species and to conduct small-scale field experiments in several parts of China, including the Jiangsu Province. Chen (2008) mentions clover, switchgrass, miscanthus, phalaris, cassava, sugar cane, and sweet sorghum as promising "energy grasses". Liu et al. (2008) use field experiments in Dafeng county, Jiangsu Province, and the city of Laizhou in the Shandong Province to confirm the seawater-tolerance and high-yield rates of particular varieties of glucide bioenergy (Helianthus Tuberosus) and bio-oil plants (Oleic sunflower). These varieties are especially suitable for cultivation in coastal mudflats. Based on the reviewed literature, the yields of four promising energy crops in China (switchgrass, silverrreed, giantreed and miscanthus) are summarized in Table 3-5. Note that all of these data were established in small-scale experiments under controllable conditions.

Table 3-5 The annual yields of potential energy crops in China (tonnes/hectare)

Switchgrass	Silverreed	Giantreed	Miscanthus	Data source
23.8	39.5			Li, 2009
5.2-11				Du et al., 2010
12				Liu et al., 2009
231	39.051	34.461		Haitao et al., 2008
8-35		5-35	10-40	Xie et al., 2008
20.03	32.11	28.75	29.96	Zong et al., 2012
14.2			11.7	Li et al., 2007
			37.5, 43.76, 4.33-14.77, 18.49-20.36, 39.05[2]	Li and Zhou, 2012
28.05	28.95	34.35		Hou et al., 2011b
3.77	11.45			Xincun et al., 2011
10-25		15-35	15-30	Xie et al., 2007
6.77, 15.41, 28.33, 27.90[3]	7.0, 17.6 29.6, 28.2[3]	16.1, 30.4, 34.4, 34.3[3]		Fan et al., 2010a

Notes: 1. This data is obtained from switchgrass of the 2nd year and silverreed and giantreed of the 3rd year. 2. The first two data-sets were obtained in Heilongjiang and Shandong, and the last three data-sets are collected in Beijing reflecting the yields of miscanthus in its 1st, 2nd and 3rd year. 3. These data-sets were collected in 2006, 2007, 2008 and 2009 respectively.

In view of the limited availability of data, we tentatively suggest the introduction of the energy crops listed above as candidate species for the Jiangsu Province. As most of the data were collected in other regions of China, the yields of these candidate species in Jiangsu Province should be verified through local field experiments.

- The mudflat as a candidate arable land resource

The experience with bioenergy development in Europe and the US shows that avoidance of food security conflicts is a precondition for a successful introduction of energy crops (Scheffran, 2009, Scheffran, 2010, Thomas et al., 2009, Tirado et al., 2010). To avoid or mitigate land use conflicts with food crops, energy crops may be planted on marginal or degraded lands (Schröder et al., 2008, Tang et al., 2010) or inserted as catch crop into crop rotations (Schönhart et al., 2011). For the Jiangsu Province, however, there exists yet another, a third option – the utilization of mudflats.

The Jiangsu Province is located on the eastern coast of China and has a non-reclaimed mudflat of about 500,000 hectares. This area consists of a supratidal belt (30,000 hectares) and an intertidal belt (470,000 hectares) and is mainly situated in Lianyungang (19,520 hectares), Yancheng (140,000 hectares) and Nantong (138,000 hectares). If this area can be reclaimed after thoroughly evaluating the possible ecological side effects, it could be used as the biomass production base becoming a new economic engine for the Jiangsu Province. To achieve this, the governmental authority of the province approved a now official plan for the mudflat reclamation in 2010 which included an environmental impact assessment, and regarded it as an important instrumental tool for boosting the regional development of northern and central sub-regions. This plan schedules the reclamation of 180,000 hectares of mudflat between 2010 and 2020 in three periods (1: 2010-2012, 2: 2013-2015 and 3: 2016-2020). According to the result of the environmental impact assessment, the candidate areas are distributed only along the coast with high deposition speed. By deliberately keeping away from the core and buffer zones of natural reserves and special marine sanctuaries, preserving 20 estuarine beaches inside the control areas of the estuarine regulation line and retaining Jiangsu's particularly important wetland ecologies and landscapes, the reclamation in gear-shape rather than parallel shape to the coastal line is calculated to lengthen the coastal line by 384 km and maintain a large degree of the marine biodiversity. Furthermore, while 60% of the reclaimed areas will be used for agriculture and 20% for construction, the remaining 20% will be devoted to ecological protection (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010). Based on this plan, we calculated the temporal and spatial distribution of all potential mudflats for energy crop cultivation for the period between 2010 and 2020. The results are listed in Table 3-6, whereby “area” refers to the total amount of mudflats assigned for reclamation. The last three columns give the actual area of mudflats dedicated to energy crops in each period.

Table 3-6 Potential mudflats for energy crop cultivation in Jiangsu Province (10^3 ha), with total area and actual use in different periods

No.	Bank section (shoal)	County	Area	Period 1	Period 2	Period 3
A01	Xiuzhen estuary-Youwang estuary	Ganyu	1.00	0.00	0.47	0.00
A02	Xingzhuang estuary-Linhongkou	Ganyu	1.67	0.00	0.00	0.00
A03	Linhongkou- Xishu	Lianyungang	2.33	0.00	0.00	0.00
A04	Xuwei port	Lianyungang	4.67	0.00	0.00	0.00
A05	Xiaodong port-Xintan port	Xiangshui	1.33	0.60	0.00	0.67
A06	Shuangyang port-Yunliang estuary	Sheyang	1.00	0.00	0.00	0.93
A07	Yunliang estuary-Sheyang estuary	Sheyang	1.67	0.73	0.00	0.00
A08	Simaoyou estuary -Wanggang estuary	Dafeng	6.00	1.00	0.00	1.60
A09	Wanggang estuary-Chuandong port	Dafeng	5.00	2.53	0.00	2.20
A10-1	Chuandong port-Dongtai estuary	Dafeng	1.17	0.00	1.10	0.00
A10-2	Chuandong port-	Dongtai	1.17	0.00	1.10	0.00

	Dongtai estuary					
A11	Tiaozini	Dongtai	26.67	8.00	9.33	0.00
A12-1	Fangtang estuary-Xinbeiling estuary	Dongtai	3.33	1.28	1.87	0.00
A12-2	Fangtang estuary-Xinbeiling estuary	Hai'an	2.00	1.92	0.00	0.00
A13	Xinbeiling estuary -Xiaoyangkou	Rudong	4.00	0.00	3.67	0.00
A14	Xiaoyangkou- Juejukou	Rudong	12.00	1.27	0.93	1.60
A15	Juejukou- Dongling port	Rudong	21.33	2.60	2.60	8.67
A16	Yaosha- Lengjiasa	Tongzhou	29.33	0.00	3.47	15.60
A17-1	Yaowang port- Haozhi port	Tongzhou	1.92	0.45	0.40	0.00
A17-2	Yaowang port- Haozhi port	Haimen	1.92	0.45	0.40	0.00
A17-3	Yaowang port- Haozhi port	Qidong	3.83	0.90	0.80	0.00
A18	Haozhi port- Tanglu port	Qidong	3.33	0.00	1.80	0.00
A19	Xiexing port-Yuantuojiao	Qidong	3.33	0.00	1.07	0.00
A20	Dongsha	Dongtai	21.33	0.00	0.00	13.87
A21	Gaoni	Dongtai	18.67	0.00	0.00	12.13
Total			180.00	21.73	29.01	57.27

Notes: 1. Phase 1: 2010-2012, Phase 2: 2013-2015, Phase 3: 2016-2020; 2. Data source: (Development and Reform Commission of Jiangsu Province, 2010).

Since the reclaimed mudflat neither is burdened by privately held land ownership titles nor has established cultivation traditions, the reclaimed mudflat is more suitable for large-scale centralized production of biomass, provided the utilization does not cause environmental degradation and occurs in a sustainable manner. Correspondingly, the bioenergy could and should be produced with modern and relatively sustainable farm management. In view of the actual circumstances in the Jiangsu Province, it was proposed that the task of reclaiming the mudflat and subsequent planting of the energy crops should be assigned to the Jiangsu Agribusiness Group Corporation, which is a state-owned company managing 18 farms. Compared to many small peasants, this company possesses abundant capital, modern cultivation technology and advanced farm machinery. By exclusively entitling a state-owned company to reclaim the mudflat, the government can control the supply of goods with common attributes at a low administrative transaction cost. Unlike individual peasant farmers, the assembled farms belonging to the Jiangsu Agribusiness Group Corporation can act as a stronger collective player with more power to face the mono- or oligopolistic purchasers in the biomass market. However, although this mode would better balance the market forces between the supply and demand sides of the biomass market, it would simultaneously marginalize small-scale peasant farmers if not compensated by an appropriate sensitive and equitable management. In order to avoid an increasing gap between small-scale peasants and large scale farms, institutional arrangements need to be set up to secure the compatibility of this mode with the former two management methods. Examples are to deliver the legitimacy for a shift of economic power or to explore the possibility of the bioenergy plantation jointly managed by the Jiangsu Agribusiness Group Corporation and the local community.

3.4.3 Demand side construction: Integration of modern bioenergy into the energy supply system

The demand side construction of bioenergy industry is, to a large extent, an integration process of bioenergy into the existing energy infrastructure and markets, with balancing a twofold relationship between renewable energy and traditional energy as well as between bioenergy and other kinds of renewable energies. China, as a country owning a strong and effective hierarchical administrative system, has dealt with the relationship well through its three administrative levels.

3.4.3.1 Renewable energy and traditional energy

Since renewable energy is assumed to gradually fill the market space left by the supply shortage of traditional energy, the competition in the first part of the relationship is moderate, especially under the institutional guidance and control of the government during the infant stage of the bioenergy industry. For power generation, the Chinese central government has reached a compromise between the interests of bioenergy power plants and coal power plants, and paved the way for biomass access to the utility grid. Furthermore, in order to shorten the gap between supply cost and sale price, the central government offers a subsidy for biomass power plants at 0.25 CNY/kWh (National Development and Reform Commission (NDRC), 2006). As for bioethanol, its production and distribution in China is monopolized and operated by regulation in a closed system, due to concerns about food security. To date, the central government has granted production licenses to only four bioethanol plants in the entire country. They alone are entitled to use stale grains from the national food reserve system, like corn or sorghum to produce bioethanol. For the time being, all of their output may be sold solely to the two official oligopolies, the Sinopec (China Petroleum & Chemical Corporation) and CNPC (China National Petroleum Corporation), each of which has its own well-established channels of gasoline distribution in the Chinese petroleum market (Dong, 2007). Such a regulation creates a rigid bioethanol market which prevents other existing oil giants from exerting pressure on the development of the bioenergy industry in its initial stage. The restricted licensing has smoothly integrated bioenergy into the energy supply system. In terms of biogas, briquettes and chars, which are used primarily in the rural areas to fill the gap left by the absence of commercial energies, there is actually no competition between them and traditional energy.

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3.4.3.2 Bioenergy in the renewable energy portfolio

As to the other part of the relationship, the Jiangsu provincial government has provided its answer: In 2009, "The Outline for Restructuring and Revitalization of the New Energy Industry" was published. One year later, "The Program of Doubling the Emerging Industry in Jiangsu Province" was enacted. In these two schematic documents, four energy industries (photovoltaic industry, wind power industry, bioenergy industry and nuclear power industry) have been confirmed as emerging industries. Meanwhile, development objectives for each industry are projected, with proposing the related supportive measures, e.g. information generation, provision mechanism, technical assistance relating to biomass resources and technologies, etc. As for the county-level governments, the grassroots level administrations are more down to earth. They are responsible for overseeing and facilitating the implementation of their supervisors' guidelines, and providing forums for articulating local needs and concerns to build political consensus. Out of the experience so far, such government involvement generates a sense of ownership that is a critical ingredient for the success of bioenergy projects in the long term (Larson and Kartha, 2000). Through this top-down style of administrative management, China can effectively reach its policy goals within the projected time frame.

The Jiangsu's practice leads to two suggestions: (1) The governmental intervention for renewable energy development in developing countries is essential. This can be justified by the role of government on mandating the share of renewable energy in the country's energy mix as well as correcting market failure incurred by the positive environmental externality of renewable energy industry; (2) The optimal renewable energy portfolio is likely to be a mixture of different kinds of renewable energies. This judgement follows the ideas of (1) offering an equal development opportunity for all types of renewable energy in the initial stage; (2) nurturing the atmosphere of competitive parity when renewable energy market evolves maturely; (3) considering the limited resource potential of each single kind of renewable energy. In order to minimize the side effect of the governmental intervention, we suggest maintaining the initial support within a reasonable scale (not exceeding a relatively small overall share) and meanwhile, valuing the important role of economic efficiency in such an intervention.

3.5 Summary

The bioenergy development differs substantially between highly developed and least developed countries. By studying the local experience from the Jiangsu Province, China, we can diversify the empirical studies of bioenergy development from the perspective of an emerging economy and, meanwhile, delineate the evolutionary process of China's bioenergy development.

Since the dispersed distribution of biomass from small-peasant farmers is unlikely to quickly transform into a business sector compliant with bioenergy demand, a centralized energy generation from distributed biomass feedstock is more favorable for the Jiangsu province. Specifically a concentrated production of modern bioenergy using crop straw and energy crops appears desirable.

The development of the bioenergy industry involves both supply side and demand side construction. The supply side construction means integrating the bioenergy supply chain management into China's overall agricultural reform. This integration process can be completed in two steps: First, the energy value of crop straw must be assimilated into the current agricultural system. Second, the cultivation of dedicated energy crops on marginal lands and mudflats mark the transition towards an “energy-oriented” agricultural system.

On the other hand, demand side construction refers to the access of bioenergy to the existing energy supply system. Due to the imperfection of market economies in the vast majority of developing countries as well as the importance of support from the government for emerging industries, the government-led model may actually prove a more feasible alternative. Besides, the role of market mechanisms should not be ignored, nor should be the issue of environmental sustainability and food security.

4 Bioenergy and land use: a spatial-agent dynamic model of optimized agricultural land use for Jiangsu in China[1]

4.1 Introduction

The objective of future energy policy is to assure the economically and environmentally sustainable supply of energy. Concerns about energy security and climate change induced by fossil energy have led to advancements in bioenergy utilization over the past decades in the US and many European countries (Hall and House, 1993, Jungmeier and Spitzer, 2001, Scheffran and BenDor, 2009). In many developing countries, bioenergy is also seen as an opportunity to boost the development of the agricultural sector and rural areas (Demirbas and Demirbas, 2007, Silveira, 2005).

In China, such motivations are reflected through a series of bioenergy supporting laws and regulations issued in recent years both at the state and provincial levels. Notable examples of these legislations are shown in Table 4-1.

Meanwhile, the Chinese government has specified concrete development targets for the bioenergy industry in its official document "*The Development Plan for Bioenergy in the 12th-five year*". By the year 2015, the installed capacity of biomass power generation is planned to reach 13 GW, annually producing about 78 billion kWh electricity. In addition, the governmental target includes 10 million tonnes (Mt) of pelletized solid fuels, 22 billion m^3 of biogas, and 5 Mt of liquid fuels (China National Development and Reform Commission (CNDRC), 2012).

The bioenergy feedstock can be produced from the biomass of conventional or energy crops. However, the large-scale introduction of biomass for bioenergy production raises concerns over food security, biodiversity, water scarcity, soil fertility and other environmental issues

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[1] This chapter was firstly presented in the "12th IAS-STS Annual Conference" and is to be submitted to the peer reviewed journal "Energy Policy".

(Dauber, Jones, 2010, Sagar and Kartha, 2007, Ugarte and He, 2007). The experience of bioenergy development in the EU and US shows that abatement of land use competition and conflicts facilitates the introduction of energy crops. The avoidance of severe conflicts between food and bioenergy production is especially important for China, a country accommodating the largest population in the world (Scheffran, 2009, Scheffran, 2010, Thomas, Choi, 2009, Tirado, Cohen, 2010). Several pilot studies have assessed the role of energy crops in China and discussed the practicability of their presence in current agriculture system qualitatively (Shao and Chu, 2008, Zhuang et al., 2011, Zong, Guo, 2012). However, qualitative analyses are usually general and lack flexibility. When facing the task of guiding the implementation of bioenergy projects in China, existing research is far less enough. Thus, conducting research simulating the optimal spatial and temporal land use pattern in the context of energy crops participation is not only an improvement of former studies but is also holding a strong practical significance.

Table 4-1 Bioenergy development supporting legislation in China

Level	Name	Year
State	Proposals for Implementation of Tax Support Policy on the Development of Bioenergy and Biochemical Industry	2006
	Interim Management Measures of the Special Funds for Renewable Energy Development	2006
	Interim Management Measures of the Subsidy of Straw for Energy Use	2008
	Proposals for Promoting the Comprehensive Utilization of Crop Straw	2008
	Renewable Energy Law of the People's Republic of China (2009 Amendment)	2009
Provincial	The Scheme for New Energy Industry Restructuring and Revitalization in Jiangsu Province	2009
	Development Plan for Coastal Area of Jiangsu Province	2009
	Development Plan for Modern Agriculture in Coastal area of Jiangsu Province	2009
	Development Plan of Mudflats in Jiangsu Province	2010

To avoid or mitigate land use conflicts, energy crops can be planted on marginal or degraded lands (Schröder, Herzig, 2008, Tang, Xie, 2010) or be inserted into crop rotations (Schönhart, Schmid, 2011). In China, some prior analyses have explored the potential use of mudflats for the plantation of energy crops (Liu et al., 2004, Wang and Zhu, 2009, Zhang et al., 2004). The value of mudflats has been recognized by the local governments and included in their development plan (Development and Reform Commission of Jiangsu Province, 2010). However, the role of reclaimed mudflats for alleviating land use conflicts and food scarcity lacks solid quantitative proof and thus, hampers the efficient development of this resource.

This study uses a dynamic, regionalized agent-based agricultural decision model to examine the optimal land use between conventional and energy crops. We quantify the contribution of mudflats to alleviate land use conflicts and food scarcity.

The chapter is structured as follows. First, we provide background information on the case study region and discuss particular characteristics relevant to the cultivation of energy crops. Next, we describe the mathematical structure, the implementation of data, and the validation of the agent-based model. Subsequently, we show and discuss the results for a series of model simulations. Finally, we conclude this research by pointing to possible improvements of our model.

4.2 Background on the bioenergy industry in the Jiangsu province

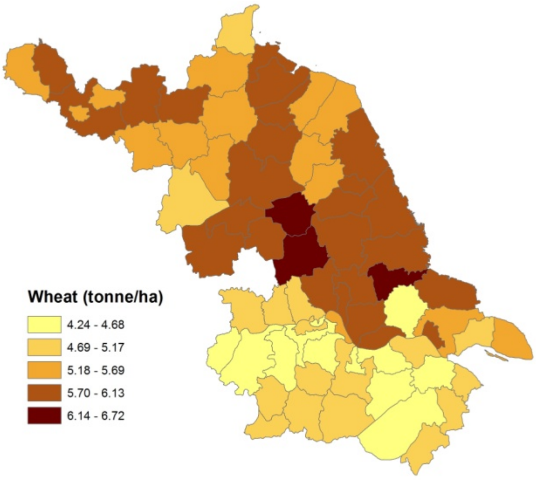
4.2.1 The study region

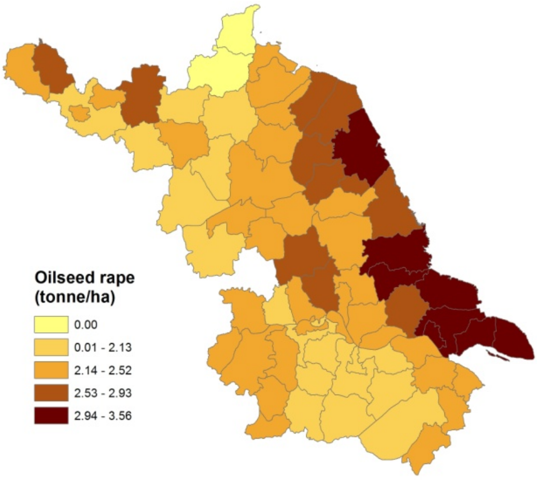
Jiangsu Province is located on the eastern coast of China. Together with Zhejiang Province and the city of Shanghai, it constitutes one of the most advanced areas in China, often referred to as the Yangtze River Delta Economic Circle (see Figure 3-1 in last chapter). Increasing levels of energy consumption in the province’s boosting economy together with intensified international pressure on curtailing GHG emissions have created an opportunity for the growth of modern bioenergy. On the supply side, excellent agricultural infrastructures, such as an efficient irrigation system, advanced machineries and a mature technical supporting network, and the availability of additional land resources, i.e. reclaimed mudflats, may provide the necessary biomass feedstock for a large-scale bioenergy industry development in the Jiangsu province.

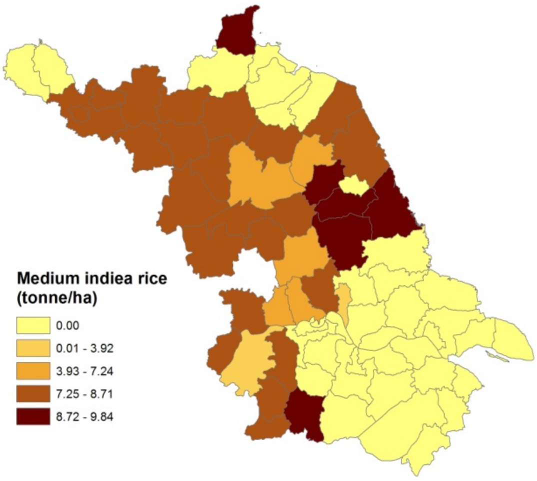
4.2.2 Conventional crops

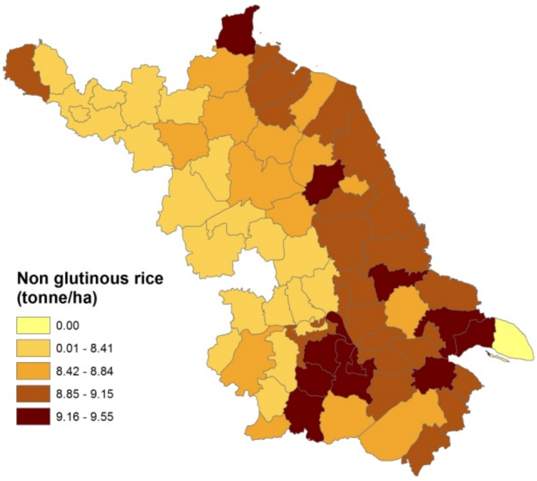
In the model setting of our study, we distinguish conventional crops and energy crops. Conventional crops include all major annual crops which are "conventionally" planted in the Jiangsu province for the purpose of food, fodder and industrial material production. The crop straw from conventional crops is considered to contribute substantial quantities of biomass feedstock in the Jiangsu Province even after the introduction of energy crops.

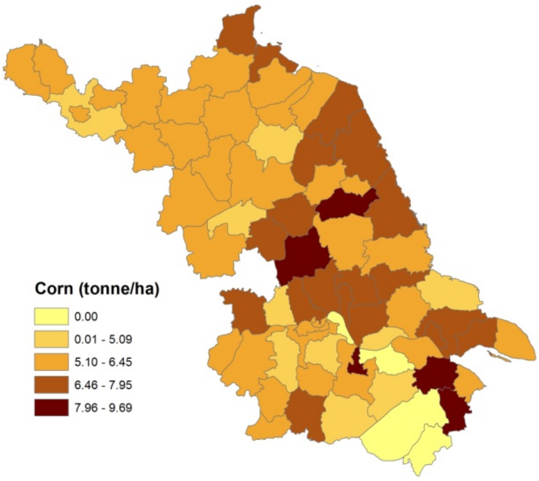
According to the official statistics (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010), the straw from wheat, oil-seeds, medium-indiea-rice, non-glutinous-rice, corn, cotton and beans accounts for up to 88.5% of the total straw supply. These crops are planted on more than 70% of the total arable land and harvested either in summer or in autumn. Therefore, our model is also designed to reflect this rotation cropping system. To demonstrate the collected data clearly, in Figure 4-1 we use the polygons with five scale darkness to represent the different levels of the yield per hectare of seven main crops in 70 counties of the Jiangsu province in 2010, which is realized on ArcGIS 10.2 platform.

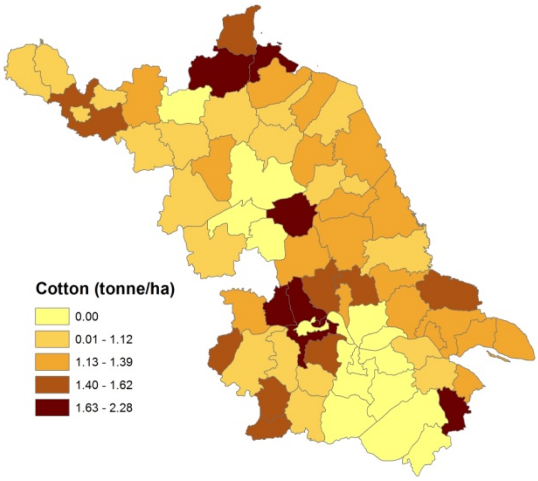

Wheat (tonne/ha)
4.24 - 4.68
4.69 - 5.17
5.18 - 5.69
5.70 - 6.13
6.14 - 6.72


Oilseed rape (tonne/ha)
0.00
0.01 - 2.13
2.14 - 2.52
2.53 - 2.93
2.94 - 3.56


Medium indiea rice (tonne/ha)
0.00
0.01 - 3.92
3.93 - 7.24
7.25 - 8.71
8.72 - 9.84


Non glutinous rice (tonne/ha)
0.00
0.01 - 8.41
8.42 - 8.84
8.85 - 9.15
9.16 - 9.55


Corn (tonne/ha)
0.00
0.01 - 5.09
5.10 - 6.45
6.46 - 7.95
7.96 - 9.69


Cotton (tonne/ha)
0.00
0.01 - 1.12
1.13 - 1.39
1.40 - 1.62
1.63 - 2.28

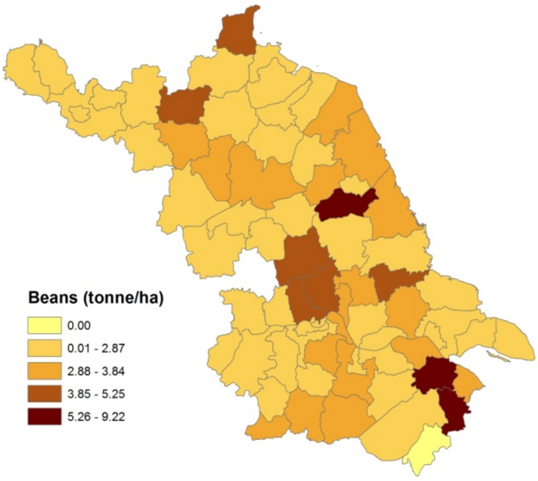


Figure 4-1 Crop yield per hectare in 70 counties of Jiangsu province in 2010

Notes: 1. Data source: Statistic Yearbook of Rural Area in the Jiangsu Province (2011).

2. For the areas with yield data of 0.00, there is no plantation for that crop.

Cultivation cost data are obtained from the annual "Cost-Benefit Investigation of Jiangsu Agricultural Products" conducted by the Cost Investigation Supervision Branch of the Jiangsu Commodity Price Bureau. The available data span five years from 2006 to 2010 and were compiled from answers to a questionnaire randomly distributed to farmers across representative 57 counties belonging to 13 prefecture-level cities. Figure 4-2 illustrates the average costs for the six main crops cultivated in the Jiangsu province in 2010. In the model, the per-hectare cost data which are logged in monetary value have been converted into the amount of each input (including land, labor, fertilizer, pesticide and others), in accordance with the market price (or equivalent price) of each capital.

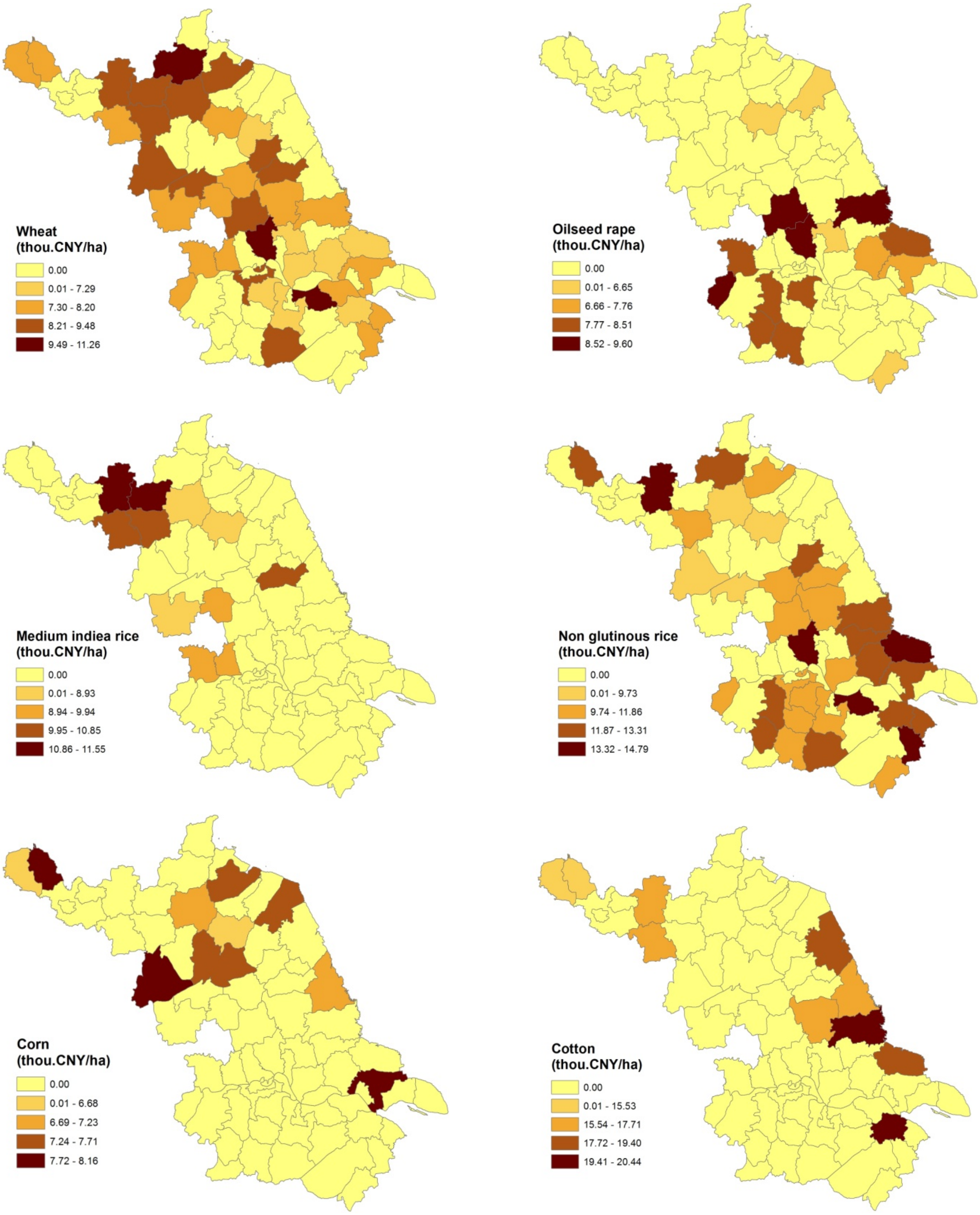


Figure 4-2 Crop cultivation cost per hectare in 70 counties of Jiangsu province in 2010

Notes:

1. Data source: Data Collection of Cost-Benefit Investigation of Jiangsu Agricultural Products (2011).

2. The crop of beans is not incorporated into the "Cost-Benefit Investigation of Jiangsu Agricultural Products". Thus, the county-level data of beans is not available.

3. For the areas containing the value of 0.00, data are not available.

As shown in the figure above, the costs of certain crops in some counties are zero. There are two reasons: first, some crops are not planted in all areas; second, the survey only includes samples from a subset of counties rather than from all counties. Therefore, for some counties where the crops may grow, they are not covered by the investigation. To remedy this data deficiency, the missing costs data are generated by interpolation of available data adopting the Ordinary Kriging Method in ArcGIS.

4.2.3 Energy crops

In the long term, energy crops are expected to fill the gap between the rising demand of biomass feedstock and limited supply from conventional crops. The promising lignocellulosic energy crops, based on existing studies, can include both perennial herbaceous crops (i.e. switchgrass, *Miscanthus*) and woody crops (such as willow, poplar, *Eucalyptus*) (Bauen et al., 2009).

While many countries have witnessed a growing level of energy crops cultivation, large-scale commercialized energy crop plantations are still absent in China. In consequence, we have not observed cultivation data for these commercial energy crops. However, with the support of relevant national and provincial policies, a number of research institutes have in recent years engaged in species selection and have conducted small-scale field experiments in certain parts of China, including the Jiangsu Province. In this study, we use the results from these experiments. Existing research shows that in the 3rd year the crops reach a mature stage with their yields remaining at a stable level thereafter (Haitao, Yang, 2008). We mimic this finding in our model by assuming constant yields for energy crops after the third year. In terms of their life span, 10 years are set to switchgrass, silverreed, and giantreed and 20 years to miscanthus.

After selecting the species of energy crops in our model, we need to specify their cultivation costs. Firstly, we process the experimental costs data of switchgrass, silverreed and giantreed, using results from (Hou, Fan, 2011b) according to Jiangsu's local price of labor and land, and use a reseeding rate of 25% for switchgrass and 0% for the other three crops (Hou et al., 2011a, Khanna et al., 2008). Secondly, to overcome the data inaccessibility, we use cost data for switchgrass to infer the corresponding data for miscanthus. For simplicity, we assume that the ratio of the cost of switchgrass to that of miscanthus is the same both in China and in the US. Then we apply this ratio obtained from the study (Khanna, Dhungana, 2008) in Illinois, USA to the experimental data of switchgrass in China (Hou, Fan, 2011b). The resulting adaptive yields and cultivation costs of energy crops are shown in Table 4-2.

Table 4-2 Yield and cost data for candidate energy crops in Jiangsu province

Crops	Switchgrass			Silverreed			Giantreed			Miscanthus		
Items Ages	1	2	3-10	1	2	3-10	1	2	3-10	1	2	3-20
Yield (t/ha)	6.77	15.41	28.12	7	17.67	28.98	16.17	30.48	34.42	9.55	19.43	29.96
Cost (per ha):												
Seedling (CNY)	135000	33750	0	90000	0	0	90000	0	0	423705	0	0
Planting (d)	7.5	1.8	0	7.5	0	0	7.5	0	0	30.525	0	0
Maintenance (d)	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	10.425	10.425	10.425
Harvest (d)	15	15	15	15	15	15	15	15	15	44.7	44.7	44.7
Irrigation (CNY)	600	0	0	600	0	0	600	0	0	600	0	0
Water (CNY)	180	0	0	180	0	0	180	0	0	180	0	0
Electricity (kWh)	846.75	0	0	846.75	0	0	846.75	0	0	846.75	0	0
N-Fertilizer (kg)	150	150	150	150	150	150	150	150	150	165	69	103.5
O-fertilizer (kg)	0	0	0	0	0	0	0	0	0	0	0	0
Herbicide (kg)	3750	0	0	3750	0	0	3750	0	0	4125	0	0

Data source: (Fan, Hou, 2010a, Fan et al., 2010b, Hou, Fan, 2011a, Hou, Fan, 2011b, Khanna, Dhungana, 2008, Zong, Guo, 2012)

Note that these data are obtained from small-scale experiments under controlled conditions and may not reflect all uncertainties of real agricultural operations.

4.2.4 Mudflats

Previous studies have suggested that cultivating energy crops on surplus agricultural land or marginal land could mitigate the potential threat to food security (Ceotto and Candilo, 2011, Scheffran, 2010). Mudflats in Jiangsu province have been examined as potential land resource for energy crops in many studies (Ling, 2009, 2010, Wang et al., 2010), and confirmed by the local government in its "*Outline of Reclamation and Utilization Plan for Jiangsu Coastal Mudflats Resource (2010-2020)*". This guiding scheme has concretely regulated the location, acreage, and utilization of mudflats for three different stages presented in Table 3-6 in last chapter. Our model implements the projection of this guideline.

4.2.5 Biomass demand

As is the case for other emerging industries, governmental support for bioenergy is essential. The official regulations, such as binding targets or mandates, compulsory grid connection or feed-in tariffs, help to create a local biomass market. This market would then establish a price for biomass, which corresponds to the marginal cost of meeting a demand target. In this study, we directly borrow the official development target of bioenergy to specify biomass demand development.

4.3 Model design and structure

4.3.1 The framework of a spatial-agent dynamic model

Long-term observations from the real world as empirical references usually play a big role in decision-making and policy-forming activities. However, they can be inadequate in understanding the possible future behavior of complex feedback systems. This judgement can also apply to the bioenergy industry, which bridges both ecological and economic systems. Fortunately, a variety of representative models constructed in prior studies can help fill the knowledge gaps and assist in bioenergy industry planning (Lychnaras and Schneider, 2011, Scheffran and BenDor, 2009, Schneider and McCarl, 2003, Walsh, 2000).

The spatial-agent system dynamic model described in Scheffran and BenDor (2009) uses a spatial array of uniform grid cells to index the position of individual farmers in the landscape as well as their crop yields and costs so as to act as heterogeneous agents while the model constructed by Schneider and McCarl (2003) is a partial equilibrium model which links agricultural commodity markets to regionalized cropping systems. In this study, we combine features from both models: We borrow from the former's structural framework and the latter's mathematical expression to develop a new spatial-agent dynamic model of optimized agricultural land use. This model is designed to describe annually recurring farmers' decisions on the allocation of land to crop types and crop mix.

The dynamic characteristic of this model mainly arises from two factors. First, heterogeneous environmental features related to soil types, climate conditions and other variables can easily create diverse conditions for the cultivation of conventional crops, implying non-uniform opportunity costs for energy crops introduced into site-specific cultivation patterns. Second, single farmer's decisions on land use heavily depend on the whole market signals, meaning the prices of commodity markets and factor markets, which, in turn, are decided by the ability and willingness of other farmers within the system boundary to plant and cultivate candidate crops. That is to say, the famers interacting as a network of agents can aggregately change the course of energy crops introduction. Given such analysis, it is important to understand and translate into the model the process of how the individual decisions of farmer agents located in differentiated areas affect the behavior of agriculture in the province as a whole.

The aggregated farmers on the county level are spatial agents in our model. As is the reality in the Jiangsu province and commonly seen in some other developing countries, countless peasant farmers scatter over a large area. Thus it is more feasible to aggregate the farmers in each of 70 counties as distinctive agents rather than directly introduce millions of individual farmers to our model.

4.3.2 The structure of the spatial-agent dynamic model

Our spatial-agent dynamic model is constructed to emulate the decision making process of heterogeneous farmers and to assess the impact of energy crops on agriculture markets, the development of the coastal area, and environmental effects. This model includes the following key components: natural and human resource endowments, markets for agricultural production factors and for primary agricultural commodities, options for land management, regional development and agricultural, energy policies.

Similar to other mathematical optimization problems, this model is composed of an objective function and a set of constraining equations. The objective function maximizes the net present value of total agricultural economic surplus over a 25-year horizon on a year-by-year basis. The constraining equations define the convex feasible region for all variables which are listed in Table 4-3:

Table 4-3 Model equations and variables

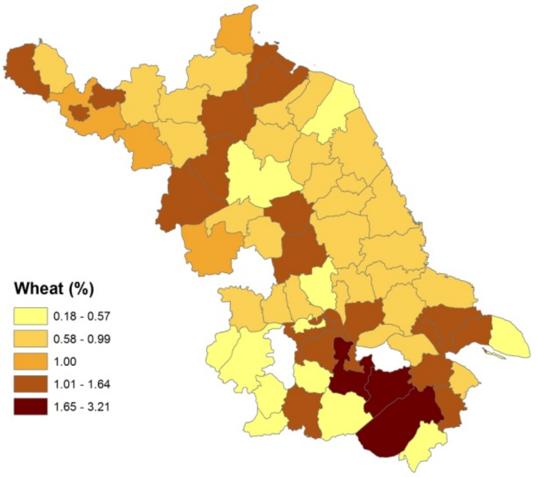
Model feature	Item	Description
Equation	Arable land limits	The cultivated and available land in each county in each year is limited to given endowments.
	Mudflat limits	According to Jiangsu's official directive, a limited area of reclaimed mudflats mainly scattered in the coastal counties can be devoted to energy crop plantations.
	Plantation dynamics	The area of energy crop plantations in higher age classes cannot exceed the area of the corresponding previous age class in the previous period.
	Crop choice	Cropping activities are restricted to a linear combination of historically observed choices. Onal and McCarl (1991) find that historical crop mix restrictions implicitly embody numerous farming constraints, which are difficult to observe. These include crop rotation considerations, perceived risk reactions, and a variety of natural conditions.
	Biomass demand	The production of biomass as feedstock for bioenergy is exogenously given.
	Food demand	Food production needs to satisfy minimum food demand.
Decision variables	The cultivated area of each crop	Cultivated area includes arable lands and mudflats. Crop refers to both conventional crops and energy crops.
	The weights of historical crop mixes	The weights of historical land use patterns for decisions on land use in future years.
	The food import and export	Inter-provincial trade

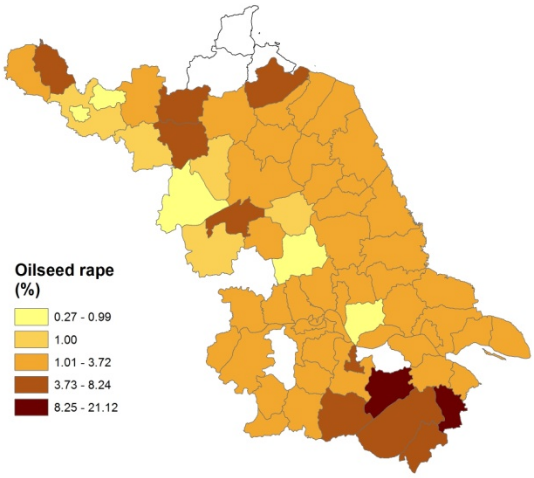
Solving the model requires finding an optimal level for all endogenous variables subject to compliance with all constraining equations. The optimal values of decision variables maximize the economic surplus of the agricultural sector. In our model, the economic surplus is computed as the sum of consumer surplus in all commodity markets, producer surplus in all factor markets and governmental net payments to the agricultural sector minus unspecific variable production cost and the cost of mudflat reclamation. As discussed by McCarl and Spreen, maximization of consumer and producer surplus yields the competitive market equilibrium. Thus, the optimal variable levels can be interpreted as likely equilibrium levels for agricultural activities under given economic, political and technological conditions. Simultaneously, the shadow prices, identical to the marginal values of the biomass and food demand constraint equations, give market-clearing prices of food and biomass feedstock. A detailed description of spatial-agent dynamic model is presented in the appendix.

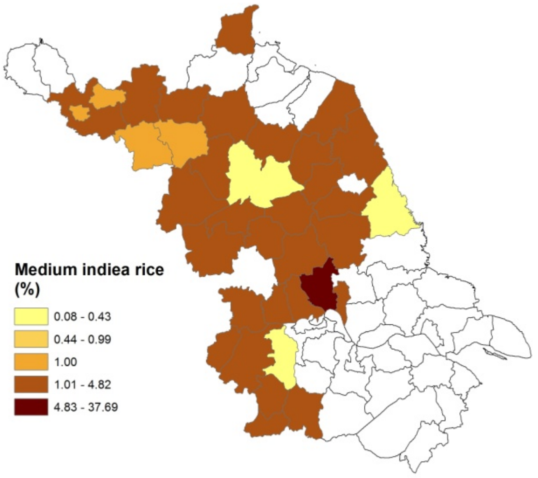
4.4 Simulation results

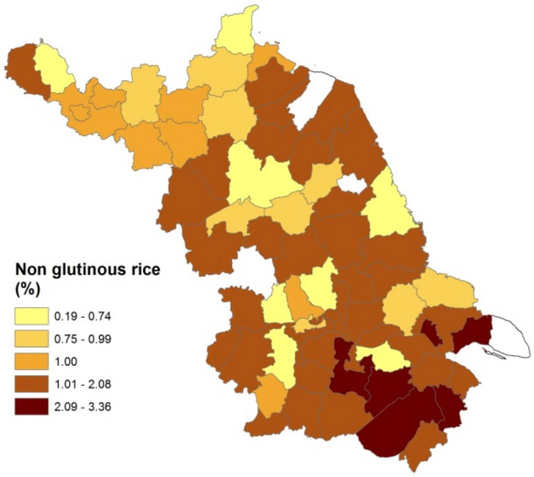
4.4.1 Land use change in facing the introduction of energy crops

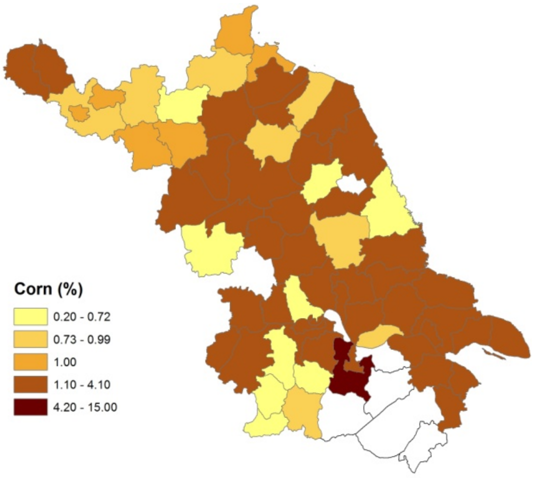
Derived from historically observed data of land use patterns in the Jiangsu province, this model offers us the optimal path of biomass feedstock supply facing a continuously growing biomass demand, and depicts the land use for conventional crops and energy crops year by year. For simplicity, here we only focus on land uses in the year 2030, the final year of the model's timeframe. Due to the absence of real energy crop plantations, the land uses for conventional crops and energy crops are presented in two different ways: For the conventional crops, their land use changes are represented in Figure 4-3A, which are obtained by comparing the cultivated area of each crop in 2030 from our model result with those in 2010 from historical data. Meanwhile, the land use for energy crops is directly picked from the simulation result and plotted in Figure 4-3B.

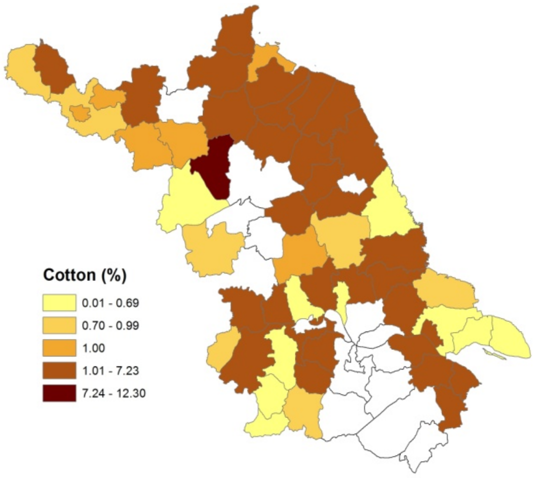

Wheat (%)
0.18 - 0.57
0.58 - 0.99
1.00
1.01 - 1.64
1.65 - 3.21

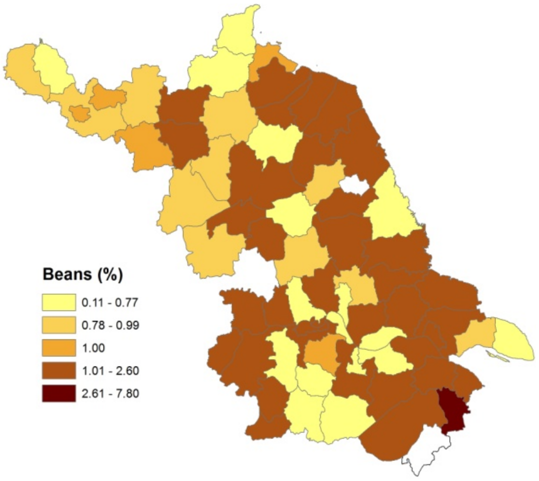

Oilseed rape (%)
0.27 - 0.99
1.00
1.01 - 3.72
3.73 - 8.24
8.25 - 21.12


Medium indiea rice (%)
0.08 - 0.43
0.44 - 0.99
1.00
1.01 - 4.82
4.83 - 37.69

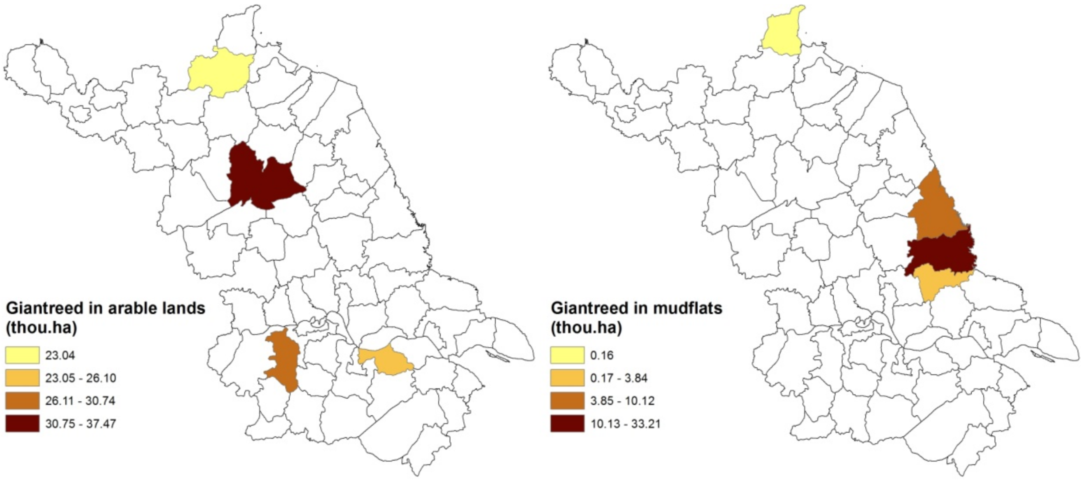

Non glutinous rice (%)
0.19 - 0.74
0.75 - 0.99
1.00
1.01 - 2.08
2.09 - 3.36


Corn (%)
0.20 - 0.72
0.73 - 0.99
1.00
1.10 - 4.10
4.20 - 15.00


Cotton (%)
0.01 - 0.69
0.70 - 0.99
1.00
1.01 - 7.23
7.24 - 12.30



(A) Relative change in cultivated area in Jiangsu province between 2010 and 2030



(B) Cultivated area of energy crops in Jiangsu province in 2030

Figure 4-3 The projected pattern of land-use change in Jiangsu province in 2030 after introduction of energy crops

Notes: 1. Data source of land use pattern in 2010: Statistic Yearbook of Rural Area in the Jiangsu Province (2011). 2. The white polygons mean that there is no plantation of certain kinds of crop in the corresponding counties.

The land use pattern reveals two characteristics: (1) The expansion of summer crops, i.e. wheat and oilseed rape in this model are mainly concentrated in southern Jiangsu, with oilseed rape having a tremendous boost (for example, its cultivated area has expanded 20 times in Wuxi city, 13 times in Kunshan county), thanks to its higher output of unit biomass output compared to wheat. (2) Among the autumn crops, no counties appear to be attractive to all crops, reflecting a differentiated land use pattern for different crops. For non-glutinous-rice, a crop planted broadly in autumn, its enlargement can be mainly found in southern Jiangsu, whereas the preferred area for cotton plantation is northern Jiangsu. For cotton, the promising cultivated area is located generally along the axis stretching from northwest to southeast, crossing the southern part of northern Jiangsu and the whole central Jiangsu. Medium-indiea-rice is mainly scattered along the east boundary of the Jiangsu province. Compared to other autumn crops, the general pattern for beans plantation, however, cannot be directly drawn from the figure.

In terms of energy crops, they are designed to be planted both on arable lands and newly reclaimed mudflats. Given the biomass utilization targets, the energy crops are seen to be introduced to the arable lands in only four out of seventy counties (i.e. in Jiangyin, Donghai, Huai'an and Jurong county) and to the reclaimed mudflats in four out of ten counties (Hai'an, Ganyu, Dongtai and Dafeng county). When focusing on the arable lands for energy crop plantations, it is unsurprising to see that the allocation of arable lands between energy crops and conventional crops are complementary to each other. The contracted areas for conventional crops in these four counties have virtually paved the way for introduction of energy crops. In other words, our model suggests the plantation of energy crops to be started from these counties.

In addition, the model has simultaneously demonstrated that giantreed, among four kinds of energy crops, is the most profitable type for our case region, a simulation result that can support strategies for promoting energy crops. But this conclusion heavily relies on the calculation of cost and benefit data without taking into consideration the potential biodiversity risk and other environmental side effects, as this kind of information cannot be exploited from small-scale experimental data.

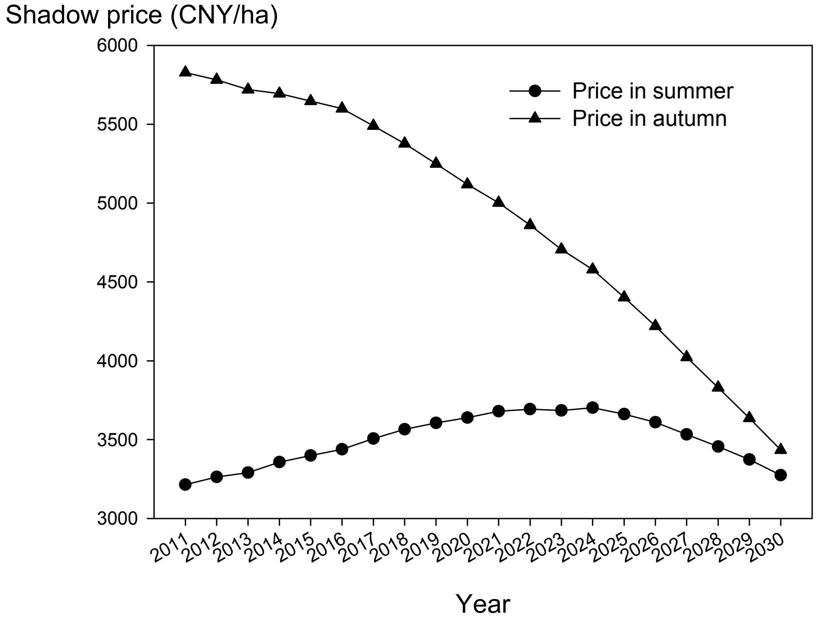


Figure 4-4 The projected shadow price of arable land in summer and autumn in Jiangsu province between 2011-2030

Figure 4-4 presents the rent of arable lands for biomass feedstock production, both in summer and autumn. The two curves in the figure vividly describe the farmers "self-adaptation process" and hence can be regarded as "learning curves" of farmers.

Because of the unprecedented introduction of biomass demand in 2011, the farmers familiar with their custom land use patterns are reluctant to react to the new requirement, corresponding to a high rent of arable lands for biomass production. Thanks to the farmers' annual decision making on land resources allocation, they can be trained on how to simultaneously balance the needs of both food and energy. When the farmers get more and more experienced, the rent of arable lands could correspondingly go down. But nevertheless, the rent of arable lands in summer soars during the initial years, as the biomass demand stimulates the expansion of cultivated areas of both wheat and oilseed rape. Besides that, the seasonal differences of land rent are expected to be faded out along with the optimization of land use. This behavior can be ascribed to the introduction of energy crops, which functions as a bridge to connect the land use patterns in summer and autumn.

4.4.2 Biomass feedstock supply

Following the analysis above, the sources of biomass feedstock supply are already clear (Figure 4-5). The straws from conventional crops constitute the main source of biomass feedstock, contributing more than 85% of the total supply. Among those, two large-scale planted crops (wheat in summer and non-glutinous-rice in autumn) lead the sources. Following those are corn, oilseed rape, medium-indiea-rice and beans. Cotton is the smallest contributor. Their relative positions in the biomass supply ranking list hold unchanged throughout the twenty years of projection, reflecting a stable reproduction of the crop mix described in the item of crop choice in Table 4-3.

Different from the expansion of conventional crops, the participation of energy crops has dramatically enhanced during the same time period, with their share to the total biomass supply soaring from just 2% in 2011 to 15% in 2030. Furthermore, disclosed by our model, the energy crops are firstly suggested to be planted on reclaimed mudflats and then on arable land. However, the amount of biomass from energy crops on arable land experiences a speedy growth and is expected to surpass the part from mudflats in the year 2029. Actually, since 2024 the cultivated area of energy crops on mudflats is leveling out at around 47 ha, forcing the biomass output from this area to reach a plateau at 1.5 million tonnes.

Besides plotting the composition of biomass feedstock, Figure 4-5 draws out its shadow price under the current policy conditions, reflecting the unit price of biomass the society is willing to pay. Due to the model's dynamic characteristic, we compute a 10-year moving average value of the shadow price and this number, as shown in Figure 4-5, keeps on growing. This happens because along with the soaring biomass feedstock demand, the competition between conventional crops and energy crops for favorably limited resources, including arable lands, labors, fertilizers, pesticides and so on, becomes fierce, implicating an increasing opportunity cost of biomass production. This increasing tendency sustains across the whole timeframe though, with a clear turning point of the growth rate in 2024, when the momentum apparently weakens. Such phenomenon can be explained by the use of mudflats, the cost of which greatly outweighs other factors. As we have analyzed before, since 2024 the newly reclaimed mudflats for energy crop plantations are so few that they can be neglected. Therefore, this expenditure can be cut off from the total expenditure, which significantly slows down the increasing pace of total cost.

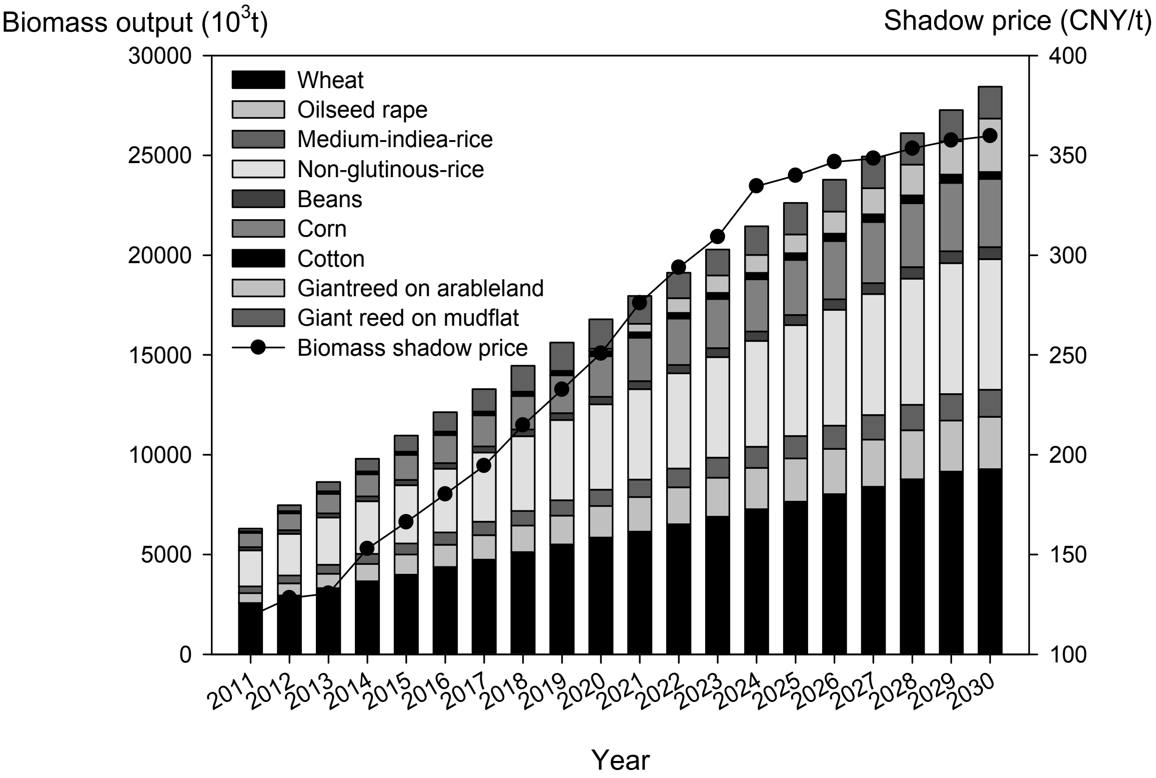


Figure 4-5 The projected biomass feedstock supply and its shadow price in Jiangsu province between 2011-2030

4.4.3 Sensitivity analysis 1: Biomass feedstock demand

As we repeatedly mentioned, the simulation results represent an optimal solution to meeting the biomass feedstock demand set by the official development plan. This implies that the biomass feedstock supply and the corresponding land use change are highly relevant to this given precondition. In order to test the robustness of conclusions drawn under the basic scenario as well as to explore the land use change to other bioenergy development targets, a sensitivity analysis on biomass feedstock demand is introduced in this section. Specifically, four alternative biomass demand scenarios are employed. While two scenarios are set to simulate the reduced demand, the other two are designed to the amplified demand (Figure 4-6).

4.4.3.1 Competition between conventional and energy crops

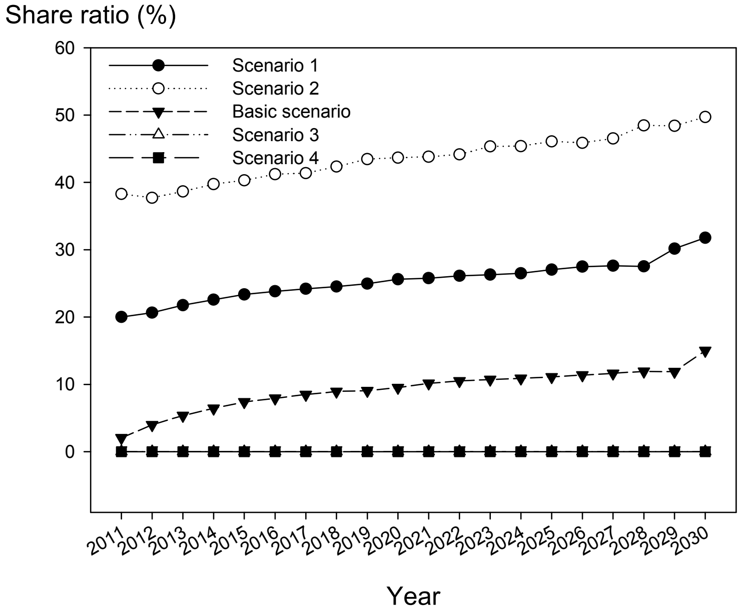


Figure 4-6 The projected share of biomass from energy crops in biomass feedstock supply in Jiangsu province between 2011-2030

Note: Under scenario 1 and 2 (amplified demand scenarios), the given biomass demand equals to 1.2 and 1.5 times the amount of the basic scenario, respectively. In scenario 3 and 4, the respective demand multipliers are 0.5 and 0.8.

By comparing the shares of biomass feedstock from conventional crops and energy crops, we can conclude that while straw from conventional crops holds the predominant status in the biomass supply, energy crops play a subordinate and complementary role. This land use pattern involving both conventional crops and energy crops is, on the one hand, a compromising result of the model, balancing all the physical and societal constraints; and, on the other hand, a cost-effective way to supply sufficient biomass and maintain food security by means of fully exploiting the dual-use of conventional crops (both food and energy use) and the single-use of energy crops (only energy use). A gradual and small-scale introduction of energy crops at the initial stage suggested by the model helps to realize a smooth transition process of the local agriculture sector switching from food-oriented to both food- and energy-oriented, and to avert the potential resistance from local farmers heavily relying on their familiar cultivation customs. However, it is worth noting that all the planning of energy crops discussed here is based on the condition of the approved biomass feedstock demand, which serves virtually as a guidance to regulate the development direction and scale of the bioenergy industry. Different development targets should probably lead to their corresponding land use patterns. And this argument can be verified by the following sensitivity analysis. We find that the land use pattern before and after the introduction of energy crops is highly sensitive to the level of biomass demand. For example, once the target rises by 20% (scenario 1), the share of energy crops in biomass supply will ascend by more than 15%. If the goal is set higher by another 30% (scenario 2), the responsive energy crops will contribute half of the supply in the terminal years, increasing by about 35% compared to its performance in the basic scenario. Instead, once the demand curtails by 20% or more (scenario 3 and 4), energy crops will be totally ruled out from the combination of biomass supply sources. Thus, an appropriate target of biomass feedstock demand is undoubtedly a pillar of the success of popularizing modern bioenergy in the Jiangsu province.

4.4.3.2 Land-use patterns in the three sub-regions

Going beyond displays on the provincial level, the share of energy crops is also shown in a different way on the sub-region level. In general, over a period of twenty-years the change of the participation ratio of energy crops on arable lands shares a similar pattern in both seasons with only a tiny different in the absolute value of the ratio. Because of the more competitive land use allocation in autumn, the share of energy crops in this season is lower.

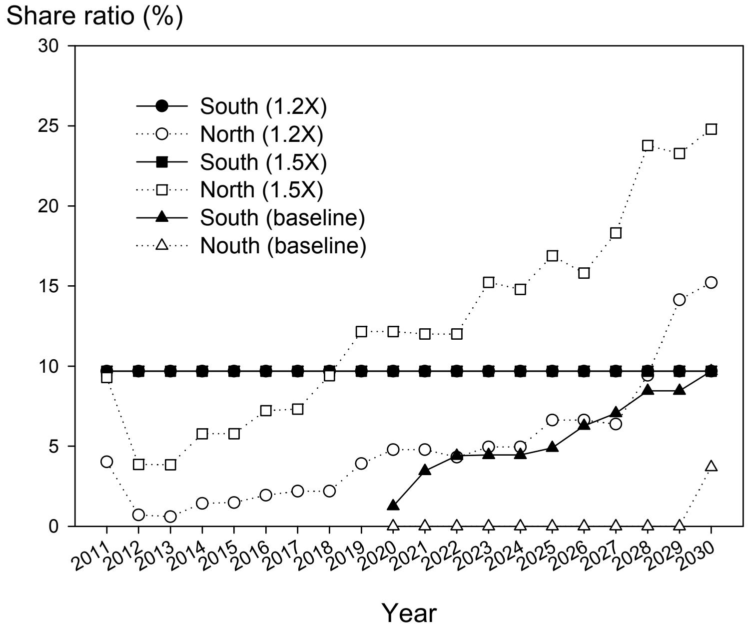


Figure 4-7 The projected energy crop share on arable land in autumn in Jiangsu province between 2011-2030

Note: Under scenario 1 and 2 (amplified demand scenarios), the exogenous biomass demands are 1.2 times and 1.5 times as much as the level in basic scenario.

Figure 4-7 delineates the cultivation of energy crops on arable land in autumn for each of the three sub-regions of the Jiangsu province. As mentioned above, there is no introduction of energy crops in the reduced demand scenarios. Thus, scenarios 3 and 4 will not be shown in Figure 4-7. Furthermore, except for the case of mudflats, energy crops are not planted on arable land in the central Jiangsu region at all. Therefore, this area is not included in the figure.

When we focus on the response of energy crops to the soaring biomass demand, a distinct hurdle of the participation ratio facing the southern part is revealed by our model. The bold lines composed of black symbols shown in Figure 4-7 suggest that the cultivation of energy crops on arable land in southern Jiangsu should not exceed about 10% of the total arable land resource, no matter what level of biomass demand is expected. This recommendation on energy crops proposed by the model reminds us of the high priority of maintaining food security in the process of promoting energy crop plantations. Although the southern part of

Jiangsu in the short term is more profitable than the northern part, the most promising area for the large-scale cultivation of energy crops, in the long term, is northern Jiangsu. This finding disclosed by our model agrees with the official orientation towards the northern part as a future bioenergy production basis, which was pointed out in the "*Development Plan for the Coastal area of Jiangsu Province*" in 2009 (China National Development and Reform Commission (CNDRC), 2009).

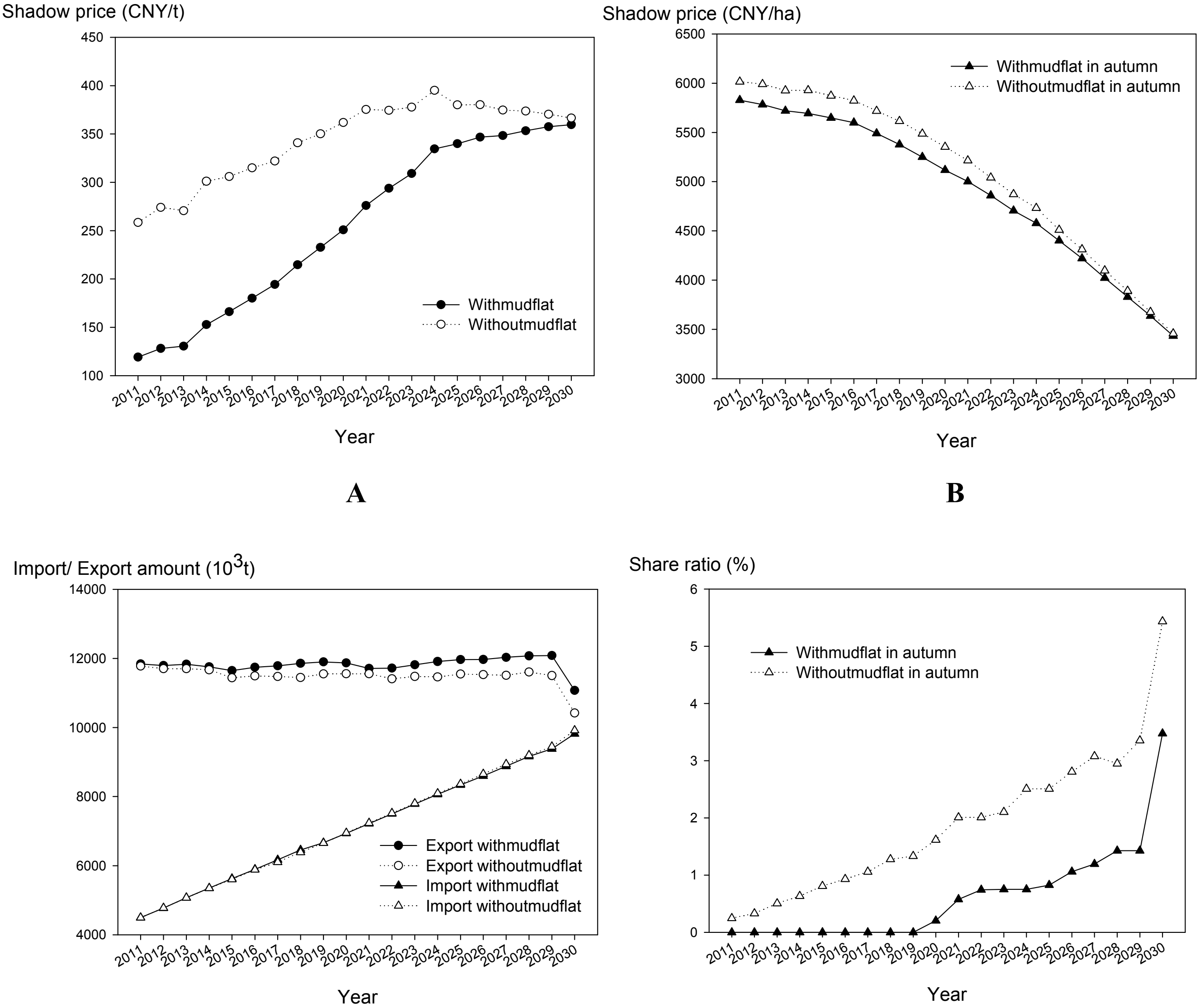
4.4.4 Sensitivity analysis 2： The role of mudflats

This section analyzes the value of mudflats for the realization of bioenergy targets. We compare the basic scenario, where a certain fraction of mudflats is available for energy crops, with a situation in which all mudflats are excluded. Figure 4-8 shows the role of mudflats using four indicators.

According to our model results, we can draw the general conclusion that the availability of mudflats for energy crop plantations can significantly alleviate land use conflicts in all aspects. It substantially lowers the prices of both biomass feedstock and arable land. For example, the introduction of mudflats decreases the biomass price by about 100 CNY/t in early years and this more acceptable price would facilitate the market acceptance of biomass on the demand side. On the supply side, mudflats reduce the rent of arable lands by 150 CNY/ha in autumn on average.

In addition, the mudflats help to produce an additional amount of about 0.75 million tonnes of food for cross-boundary food trade (0.65 million tonnes more wheat and medium-indiea-rice for export, 0.10 million tonnes less beans and corn for import in 2030), accounting for 3.59% of total amount of food trade in the same year. Besides that, they can save up to 2% of the total arable land in the final year under the basic scenario.

However, from the view of time scale, the impact of mudflats on these four indicators performs differently. For shadow prices of biomass feedstock and arable land, the gap between scenarios with and without mudflats are diminishing along with the promotion of energy crops. This is believed to be the consequence of the self-adaptation of the farmers simulated by our optimization model. Mudflats, as the replacement of arable lands for energy crop plantations, can actually function as a safe cushion against the potentially dramatic land use change facing unprecedented biomass needs. And in pace with the downward learning curve of farmers, the buffering action offered by mudflats disappears in the end.



A B

C D

Figure 4-8 The role of mudflats in (A) biomass shadow price, (B) arable land shadow price, (C) food trade and (D) fraction of energy crops in arable land in Jiangsu province between 2011-2030

To the opposite, in terms of food trade, the effect of mudflats has enhanced rather than weakened in the future. This can be explained by the increasing usage of arable land for energy crops. Without the participation of mudflats, the needed energy crops will be exclusively planted on arable lands and correspondingly, the total area for food crops is forced to be contracted, leading to an increasing loss of food production. Besides, the difference in the ratio of shares for the two scenarios of the fourth indicator exactly equals the portion of energy crops planted on mudflats. Echoing the usage of mudflats discussed before, the gap between the two curves enlarges at first and then keeps stable since the year 2024.

4.5 Conclusions and discussion

In this analysis, we have studied the economic feasibility of a planned development target of the bioenergy industry in the Jiangsu province and the implications of this development plan for agricultural land use. In addition, we have examined the land use changes on the provincial and sub-regional level under different development targets and the role of mudflats on alleviating land use conflict. From our simulation, some insights can be gained: (1) Facing the introduction of energy crops, there is a seasonal difference in land use change. For summer crops, the expansion of their cultivation mainly occurs in northern Jiangsu. But there is no such a uniform pattern for all crops in autumn. (2) Energy crops are suggested to be introduced first to Jiangyin, Donghai, Huai'an and Jurong counties on their arable lands and on reclaimed mudflats in Hai'an, Ganyu, Dongtai and Dafeng counties. The most profitable energy crop is giant reed. (3) Compared to the biomass from energy crops, the straws from conventional crops contribute the absolute majority of biomass supply, accounting for more than 85% of the total amount. Among these crops, wheat and non-glutinous-rice top the chart of biomass feedstock supply and are followed by corn, oilseed rape, medium-indiea-rice, beans and cotton. (4) On the provincial level, the spatial distribution and plantation scale of energy crops heavily rely on the bioenergy development target. The model shows that an 80% amount of the officially approved biomass demand can directly lead to the elimination of energy crops on Jiangsu's soil. (5) On the sub-regional level, the model recommends the introduction of energy crops starting from southern Jiangsu. But in the long term, northern Jiangsu becomes the main bioenergy production basis. (6) Reclaimed mudflats, as the replacement of arable lands for energy crop plantations, are quite helpful in alleviating the potential land use conflict incited by the introduction of unprecedented biomass feedstock production. The quantitative results demonstrate that mudflats can reduce the biomass price by 100 CNY/t and arable land cost by 200 CNY/ha, produce an additional amount of 0.75

million tonnes of food for its across-boundary trade, and save up to 2% of arable land on average. But, in the meantime, we need to notice that this relief effect would gradually be eroded by the farmers' self-adaptation mechanism.

Considering its limitations, this model can be extended in the following two directions: First, the import of high-qualified field data of energy crop plantations, which is believed to greatly advance the prediction of energy crop selection and distribution. Besides that, parallel to the independent but inter-linked biomass supply agents, the biomass demand side can also be deconstructed into different kinds of biomass utilization agents, for example, the biorefineries and biomass-based power plants in the Jiangsu province. More research on the biomass feedstock demand side would be meaningful.

Appendix II The spatial-agent dynamic model specification

The general formulation of the county-level dynamic agent-based model maximizes the present value of the total profits across the whole time frame of a system covering the cultivation of both conventional crops and energy crops, subject to resources endowment constraints, energy crops transition constraints, cultivation selection constraints and product demand constraints.

Indices:

u: county-level regions /Nanjing, Pukou, Liuhe, Shushui, Gaochun, Wuxi, Jiangyin, Yixing, Xuzhou, Fengxian, Peixian, Tongshan, Suining, Xinyi, Pizhou, Changzhou, Wujin, Liyang, Jintan, Suzhou, Changshu, Zhangjiagang, Kunshan, Wujiang, Taicang, Nantong, Tongzhou, Hai-an, Rudong, Qidong, Rugao, Haimen, Lianyungang, Ganyu, Donghai, Guanyun, Guannan, Huai-an, Lianshui, Hongze, Xuyi, Jinhu, Yancheng, Yandu, Xiangshui, Binhai, Funing, Sheyang, Jianhu, Dongtai, Dafeng, Yangzhou, Baoying, Yizheng, Gaoyou, Jiangdu, Zhenjiang, Dantu, Danyang, Yangzhong, Jurong, Taizhou, Xinghua, Jingjiang, Taixing, Jiangyan, Suqian, Shuyang, Siyang, Sihong/

fc: food crops /wheat, oilseed-rape, medium-indiea-rice, non-glutinous-rice, beans, corn, cotton/

sc: summer crops /wheat, oilseed-rape/

ac: autumn crops /medium-indiea-rice, non-glutinous-rice, beans, corn, cotton/

pc: perennial crops /switchgrass, miscanthus, silverreed, giantreed /

pr: products /wheat, seeds, medium-indiea-rice, non-glutinous-rice, beans, corn, cotton, straw/

pr_food: non-biomass products /wheat, seeds, medium-indiea-rice, non-glutinous-rice, beans, corn, cotton/

pr_energy: products as bioenergy feedstock /straw/

t: time horizon /2006-2020/

s: the current policy scenario /s1 /

n: crop season /summer, autumn/

a: crop age /1,2,…,20/

ht: historical year /2000-2010/

inp: the input factors during crop field management /land, labor-self, labor-employed, water, n-fertilizer, p-fertilizer, k-fertilizer, o-fertilizer, pesticide, agricultural-film, diesel, electricity/

Exogenous data:

$y_{u,fc,pr,t,n}^{foodcrop}$: yield of food crop (10^3 t/10^3 ha)

$y_{pc,pr\_energy,a}^{perennial\,crop}$: yield of perennial crop (10^3 t/10^3 ha)

$ps_{pr,t,s}$: price subsidy (10^3 CNY/10^3 t)

$v_{u,pr\_food,t}^{grains}$: price of non-biomass product (10^3 CNY/10^3 t)

$sub_{u,fc,t,s}^{food\,crop}$: land subsidy for conventional crops (10^3 CNY/10^3 ha)

$sub_{u,pc,t,s}^{perennial\,crop}$: land subsidy for perennial crops (10^3 CNY/10^3 ha)

$c^{mudflat}$: reclamation cost of mudflats (10^3 CNY/10^3 ha)

$b_{u,t}^{land}$: total arable land area (10^3 ha)

$b_{u,t}^{mudflat}$: mudflats resource potential (10^3 ha)

$h_{u,fc,ht,n}$: historical cultivation data (10^3 ha)

k_{pc} : expected lifespan of perennial crops (year)

$dema_{t}^{biomass}$: demand of bioenergy feedstock (10^3 t)

$dema_{t}^{grains}$: demand of grains (10^3 t)

r: discount rate

η_u : proportion of straw for energy-end use (electricity and biofuels) to its total amount (%)

α : ratio of straw from main food crops (wheat, oilseed-rape, medium-indiea-rice, non-glutinous-rice corn, cotton, beans) to its provincial potential (%)

$restvalue_{u,pc,a}^{arableland}$: rest value of perennial crop in arable land (10^3 CNY/10^3 ha)

$restvalue_{u,pc,a}^{mudflat}$: rest value of perennial crop in mudflats (10^3 CNY/10^3 ha)

$restvalue_{u,fc,n}^{food\ crop}$: rest value of food crop (10^3 CNY/10^3 ha)

$consumption_{fc,t,inp,u}^{conventional\ crop}$: consumption of input factors for conventional crops' cultivation (10^3 ha/10^3 ha, 10^3 d/10^3 ha, 10^3 m^3/10^3 ha, 10^3 kg/10^3 ha, 10^3 kWh/10^3 ha)

$consumption_{pc,a,inp}^{perennial\ crop}$: consumption of input factors for perennial crops' cultivation (10^3 ha/10^3 ha, 10^3 d/10^3 ha, 10^3 m^3/10^3 ha, t/10^3 ha, 10^3 kWh/10^3 ha)

$v_{fc,t,inp,u}^{cc\ input}$: price of input factors for food crops (10^3 CNY/10^3 ha, 10^3 CNY/10^3 d, 10^3 CNY/10^3 m^3, 10^3 CNY/t, 10^3 CNY/10^3 kWh)

$v_{t,inp,u}^{pc\ input}$: price of input factors for perennial crops (10^3 CNY/10^3 ha, 10^3 CNY/10^3 d, 10^3 CNY/10^3 m^3, 10^3 CNY/t, 10^3 CNY/10^3 kWh)

Decision variables:

$LAND_{u,fc,t,n}^{food\ crop}$: cultivated area for food crops in arable land (10^3 ha)

$LAND_{u,pc,t,a}^{perennial\ crop}$: cultivated area for perennial crops in arable land (10^3 ha)

$LAND_{u,pc,t,a}^{mudflat}$: cultivated area for perennial crops in reclaimed mudflats (10^3 ha)

$CMIX_{u,ht,n}$: weights of historical data

$PRICE_{t}^{biomass}$: endogenous price of biomass (10^3 CNY/10^3 t)

$FOODFLOW_{fc,t}$: import or export amount of food trade (10^3 t)

Objective function:

Max WELF =

$$
\begin{aligned}
&\sum_t (1+r)^{-t}\cdot\\
&\left(\begin{aligned}
&\sum_{u,fc,pr\_food,n}\left[y_{u,fc,pr\_food,t,n}^{food\ crop}\cdot LAND_{u,fc,t,n}^{food\ crop}\cdot\left(v_{pr\_food,t}^{grains}+ps_{pr\_food,t,s}\right)\right]\\
&+\sum_{u,fc,pr\_energy,n}\left[y^{food\ crop}_{u,fc,pr\_energy,t,n}\cdot LAND^{food\ crop}_{u,fc,t,n}\cdot\left(PRICE_t^{biomass}+ps_{pr\_energy,t,s}\right)\right]\\
&+\sum_{u,fc,n}[LAND^{food\ crop}_{u,fc,t,n}\cdot sub^{foodcrop}_{u,fc,t,s}]\\
&+\sum_{u,pc,pr\_energy,a}\left[y^{perennial\ crop}_{pc,pr\_energy,a}\cdot\left(LAND^{perennial\ crop}_{u,pc,t,a}+LAND^{mudflat}_{u,pc,t,a}\right)\cdot(PRICE_t^{biomass}+ps_{pr\_energy,t,s})\right]\\
&+\sum_{u,pc,a}\left[\left(LAND^{perennial\ crop}_{u,pc,t,a}+LAND^{mudflat}_{u,pc,t,a}\right)\cdot sub^{perennial\ crop}_{u,pc,t,s}\right]
\end{aligned}\right)\\
&+(1+r)^{-t}\cdot\\
&\left\{\begin{aligned}
&\sum_{u,pc,a}\left(LAND^{perennial\ crop}_{u,pc,t,a}\cdot restvalue^{arable\ land}_{u,pc,a}+LAND^{mudflat}_{u,pc,t,a}\cdot restvalue^{mudflat}_{u,pc,a}\right)\Big|_{t='2030'}\\
&+\sum_{u,fc,n}\left(LAND^{food\ crop}_{u,fc,t,n}\cdot restvalue^{food\ crop}_{u,fc,n}\right)\Big|_{t='2030'}
\end{aligned}\right\}\\
&-\sum_t(1+r)^{-t}\cdot\\
&\left(\begin{aligned}
&c^{mudflat}\cdot\left(\sum_{u,pc,a}LAND^{mudflat}_{u,pc,t,a}-\sum_{u,pc,a}LAND^{mudflat}_{u,pc,t-1,a}\right)\\
&+\sum_{u,fc,n}\left\{\sum_{inp}(consumption^{conventional\ crop}_{fc,t,inp,u}\cdot v^{cc\ input}_{fc,t,inp,u})\cdot LAND^{food\ crop}_{u,fc,t,n}\right\}\\
&+\sum_{u,pc,a}\left\{\sum_{inp}(consumption^{perennial\ crop}_{pc,a,inp}\cdot v^{pc\ input}_{t,inp,u})\cdot\left(LAND^{perennial\ crop}_{u,pc,t,a}+LAND^{mudflat}_{u,pc,t,a}\right)\right\}
\end{aligned}\right)\\
&\forall s
\end{aligned}
\tag{1}
$$

The objective function (1) of the model maximizes the present value of the net cash flows of the agriculture sector in the Jiangsu province across the whole time frame, as the total revenue minus costs. Specifically, the revenue of agriculture sector comprises of the sale of agricultural products, governmental agricultural subsidies and terminal values[1]. The cost mainly covers land resource, labor resource, fertilizers, pesticides and other auxiliary inputs.

From line 1 to line 9, the revenue terms account for:

---

[1] Terminal Values are estimated for every crop. For energy crops, it is calculated as the Present Value of future profits of the rest of the productive life of the cultivation. This is equal to $PV=\sum_t(\mathrm{P}_t\cdot\mathrm{Y}_t-PC_t)\cdot(1+\mathrm{r})^{-t}$, where P_t is the price of the crop's product in period t, Y_t is the yield and PC_t is the production cost.

a) the sales revenue of non-biomass from conventional crops

b) the sales revenue of biomass from conventional crops

c) the plantation subsidy on conventional crops

d) the sales revenue of biomass from energy crops

e) the plantation subsidy on energy crops

f) the rest value of energy crops in the terminal year

g) the rest value of conventional crops in the terminal year

Starting from line 10 of the objective function, the cost items are:

h) the reclamation cost of mudflats

i) the cost of production inputs for conventional crops

j) the cost of production inputs for energy crops

Subject to:

The most fundamental physical constraint on crop cultivation arises from the use of scarce and immobile resources. Particularly, the use of agricultural land is limited by given regional endowments of arable land and mudflat resources. In the following expressions, $b_{u,t}^{land}$ denotes total arable land area in region u, year t and $b_{u,t}^{mudflat}$ is total arable land area for costal mudflat region in region u, year t.

$$\sum_{fc} LAND_{u,fc,t,n}^{food\,crop} + \sum_{pc,a} LAND_{u,pc,t,a}^{perennial\,crop} \leq b_{u,t}^{land} \qquad \forall u,t,n \qquad (2)$$

$$\sum_{pc,a} LAND_{u,pc,t,a}^{mudflat} \leq \sum_{t='2006'}^{t} b_{u,t}^{mudflat} \qquad \forall u,t \qquad (3)$$

Equation block (2) requires the sum of the arable lands allocated to certain types of crop plantation (including both conventional crops and energy crops) in one crop season be smaller than the amount of locally accessible arable land resources, no matter which kind of field management has been adopted. This, to some extent, reflects the fact of land use conflict between food crops and energy crops. Similarly, for equation block (3), it applies the same structure as block (2). The difference lies in that block (3) proposes the limitation on mudflat resources and reclaimed mudflats are only dedicated to *pc*, which is energy crop. As considering Jiangsu's unique feature of having large area of mudflats located along its coast, equation block (3) offers us a solution that the plantation of energy crop on mudflats may be a feasible and cost effective way to secure enough biomass provision for energy purpose while decreasing its negative influences on food security as much as possible.

$$\sum_{pc,a} LAND^{mudflat}_{u,pc,t-1,a} \leq \sum_{u,pc,t,a} LAND^{mudflat}_{u,pc,t,a} \qquad \forall u,t \tag{4}$$

Equation block (4) assures that the reclamation process is irreversible. That means the accumulated cultivation area for energy crops in mudflats can only be enlarged. This assumption is consistent with an up tendency of biomass demand.

$$\left.\begin{array}{l} -LAND^{perennial\,crop}_{u,pc,t-1,a-1} + LAND^{perennial\,crop}_{u,pc,t,a} \leq 0 \\ -LAND^{mudflat}_{u,pc,t-1,a-1} + LAND^{mudflat}_{u,pc,t,a} \leq 0 \end{array}\right|_{1<a\leq k_{pc}} \qquad \forall u,pc,t,a \tag{5}$$

Equation block (5) is targeted for perennial crops' consistency. Considering its natural death or farmers' active eradication, the plantation area of certain kind of perennial crop would never be larger but only smaller than or be equal to the area of itself in the prior year.

The fifth set of constraints addresses aggregation related aspects of farmers' decision process. These constraints force farmers' cropping activities $LAND^{food\,crop}_{u,fc,t,n}$ either in summer or in autumn to fall within a convex combination of historically observed seasonal choices $h_{u,fc,ht,n}$ (Eq. (6)). Based on decomposition and economic duality theory, Onal and McCarl (1991) show that historical crop mixes represent rational choices embodying numerous farm resource constraints, crop rotation considerations, perceived risk reactions, and a variety of natural conditions. In (6), the $h_{u,fc,ht,n}$ coefficient contains the observed crop mix levels for the latest 11 years (they are from 2000 to 2011). $CMIX_{u,ht,n}$ are positive, endogenous variables indexed by historical year and region, whose level will be determined during the optimization process.

$$-\sum_{ht}\left(h_{u,fc,ht,n} \cdot CMIX_{u,t,ht,n}\right) + LAND^{food\,crop}_{u,fc,t,n} = 0\Big|_{2010<t\leq 2030} \forall u, fc,t,n \tag{6}$$

However, crop mix constraints are not applied to the crops, which under certain policy scenarios are expected to expand far beyond the upper bound of historical relative shares (Schneider et al., 2007). As the cultivation area of energy crops is expected to greatly expanded in the future, these crops are naturally excluded from this equation block.

$$\begin{aligned}
& dema_{t}^{biomass} - \sum_{u,fc,pr\_energy,n} \eta_u \cdot \frac{y_{u,fc,pr\_energy,t,n}^{food\,crop} \cdot LAND_{u,fc,t,n}^{food\,crop}}{\alpha} \\
& + \sum_{u,pc,pr\_energy,a} y_{u,pc,pr\_energy,t,a}^{perennial\,crop} \cdot \left(LAND_{u,pc,t,a}^{perennial\,crop} + LAND_{u,pc,t,a}^{mudflat} \right) \leq 0 \\
& \forall t
\end{aligned} \tag{7}$$

The supply and demand balance of biomass is represented in equation block (7). The first item denotes the biomass demand in a certain year. The second item denotes the biomass from traditional food crops, namely crop straw and the last term represents the biomass from perennial crops grown either on arable land or reclaimed mudflats. This expression fully secures the achievement of biomass development target in due year.

$$dema_{fc,t}^{grains} - \sum_{u,fc,pr\_food,n} \left(y_{u,fc,pr\_food,t,n}^{food\,crop} \cdot LAND_{u,fc,t,n}^{food\,crop} \right) - FOODFLOW_{fc,t} \leq 0 \quad \forall fc,t \tag{8}$$

Paralleling, the last constraint set defines the satisfaction to the requirement of food security in the background of bioenergy introduction. The first item is the demand of certain food, the following items stand for the produced food from planted conventional crops, and the last item means the gap between food demand and supply is filled by across-boundary food trade.

5 Optimizing the bioenergy industry infrastructure: transportation networks and bioenergy plants locations in the Jiangsu province[1]

5.1 Introduction

Due to emerging global environmental challenges and rising global demand of energy, the developing countries are investing and designing policies for alternative sources of energy to fulfill local energy demands of growing industrial sector and rising population. According to IEA's statistic (2012), the global supply of bioenergy in 2010 reached 1277.08 Million tonnes of oil equivalent (Mtoe), ranking fourth after traditional fossil fuels- crude oil (4069.38 Mtoe), coal (3596.04 Mtoe) and natural gas (2719.10 Mtoe) but leading the contribution of renewable energy types. China has set a concrete development target for bioenergy: by 2020, its total installed capacity of biopower generation will reach 30 GW by consuming 50 Million tonnes (Mt) of solid biomass fuel, and it will produce 10 Mt of bioethanol fuel and 2 Mt of biodiesel (China National Development and Reform Commission (CNDRC), 2007).

Along with these ambitious bioenergy products mandates, considerable challenges to the bioenergy supply chain infrastructure are highly expected. Richard (2010) predicted that by mid-century biomass feedstock transport volumes are likely to exceed the combined capacity of current agricultural and energy supply chains including grain, petroleum, and coal. Therefore, in order to prevent such prediction from happening, sufficient investments are needed to overcome the technical and economic barriers across all stages of the supply chain of bioenergy- from crop plantation, feedstock harvesting, storage, transportation, and processing to bioenergy products distribution (Seelke and Yacobucci, 2007). Besides of optimal biomass feedstock supply, there are another three issues must be addressed in bioenergy industry construction: (1) the infrastructure requirements meeting local

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[1] This chapter is to be submitted to the peer reviewed journal "Energy Research & Social Science".

environmental and economic conditions; (2) an optimal design of bioenergy plants for an efficient conversion of biomass feedstock into bioenergy products through selecting appropriate processes; and (3) the cost-effective transportation and distribution networks of feedstocks and bioenergy products (Kang et al., 2010).

Although transportation service is critical for the deployment of biomass feedstock and of bioenergy plants, this field has not been fully examined by existing academic literature. On the other hand, some policy reports have acknowledged the importance of new logistics, which are derived either from the emergence of renovated supply chain required for new bioenergy projects or from extra freight transport demand. However, the researches adopting quantitative analysis tools are quite rare (Bonilla and Whittaker, 2009).

In order to fill these gaps, this chapter is to present an analytical dynamic modeling approach, which is based on our preceding optimal land use model for simulating the provision of biomass feedstock. We design this new model to determine the optimal locations and capacities of biomass-fired power plants and biorefineries, the delivery of biomass feedstock to bioenergy plants as well as the distributions of biopower, bioethanol and by-products. Furthermore, we also apply this model to evaluate the effects of two policies: the biomass preprocessing measure and the regional development policy.

Along with these ambitious bioenergy products mandates, considerable challenges to the bioenergy supply chain infrastructure are highly expected. Richard (2010) predicted that by mid-century biomass feedstock transport volumes are likely to exceed the combined capacity of current agricultural and energy supply chains, including grain, petroleum, and coal. Therefore, in order to prevent such prediction from happening, sufficient investments are needed to overcome the technical and economic barriers across all stages of the supply chain of bioenergy- from crop plantation, feedstock harvesting, storage, transportation, and processing to bioenergy products distribution (Seelke and Yacobucci, 2007). Besides of optimal biomass feedstock supply, there are another three issues must be addressed in bioenergy industry construction: (i) the infrastructure requirements meeting local environmental and economic conditions; (ii) an optimal design of bioenergy plants for an efficient conversion of biomass feedstock into bioenergy products through selecting appropriate processes; and (iii) the cost-effective transportation and distribution networks of feedstocks and bioenergy products (Kang, Önal, 2010).

Although transportation is a critical service for the deployment of biomass feedstock and of bioenergy plants, the existing academic literatures and policy reports lack in depth analysis of biomass supply chain impacts on transportation. The importance of new logistics, derived from the emergence of renovated supply chain required for new biomass projects and from extra freight transport demand, is acknowledged in the policy literatures but detailed analysis with quantitative method is rarely done (Bonilla and Whittaker, 2009).

In order to fill this research deficiency, this chapter is to present analytical dynamic modeling approach based on our preceding optimal land use model used for simulating biomass feedstock provision. The new model is designed to determine the optimal locations and capacities of biomass-fired power plants and biorefineries, delivery of biomass feedstock to bioenergy plants, and distributions of bio-power, bioethanol and by-products (bioslurry). Furthermore, the effects of biomass preprocessing measure and regional development policy can also be evaluated through this model.

This chapter is divided into five sections. Section 2 presents some background information on bioenergy utilization in the Jiangsu province and key components of the optimal bioenergy industry infrastructure problem. Section 3 describes the structure of the dynamic agent based model, the data collection and processing procedures for certain parameters. Section 4 of the study discusses the model simulation results of different tests and scenarios. In the end, section 5 elaborates the conclusion and policy implications of the study.

5.2 The optimal bioenergy production and distribution system

5.2.1 Centralized energy generation versus decentralized energy generation

Generally, with respect to utilization scale, the use of biomass feedstock can be categorized into three modes (Karekezi and Kithyoma, 2006) i.e. (i) Centralized energy generation from centralized biomass such as sugar factories which use agricultural wastes to generate heat and bio-power for their own consumption; (ii) Centralized energy generation from decentralized biomass production, e.g. the corn-based bioethanol production, and (iii) Decentralized energy generation from decentralized feedstock, such as household biogas, which is widely adopted in China (Chang et al., 2011, Feng et al., 2009). However, considering the prominent contribution of large-scale bioenergy projects to regional development through mechanisms of promoting the modernization of traditional agriculture sector, the Chinese government seems to have a strong preference for centralized bioenergy systems in recent years (He et al., 2013).

The Jiangsu Province, locating on the eastern coast of China, shares the similar situation as discussed in above paragraph. Among various bioenergy products, bio-power is the biggest energy-purpose user of crop straw (Zhang, Zhang, 2012). By the end of 2012, 30 demonstration projects of biomass-fired power plants with 0.803 GW installed capacity had been approved in the Jiangsu Province, of which 13 had already been successfully connected to the power grid. Most of these plants employ the direct combustion technology and are located in the northern and central sub-regions, digesting 3.6 Mt of crop straw (Yan, 2013) which is likely to rise to 6 Mt by 2015 (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010). As to bioethanol, E10 biofuel was officially introduced to northern Jiangsu in 2006. In accordance with an official development plan in 2008, four bioethanol plants, mainly using sweet potatoes as feedstock, will be built in the coming years in the cities of Lianyungang, Suqian, Yancheng and Xuzhou. In 2010, the annual production of E10 was estimated to have reached 4 billion tonnes (Xinhua Newspaper Group, 2008). In conclusion, the power generation and bioethanol production are the two predominant conversion processes in the Jiangsu province, which have received strong governmental support and thus developed better than other possible biomass utilization methods.

5.2.2 Bioenergy industry transportation network and bioenergy plants locations

Although the transportation network and the bioenergy plants locations are two components of bioenergy industry infrastructure, they are actually highly correlated, or even can be regarded as just two aspects of one issue. This argument can be explained by Figure 5-1.

Different from biomass' traditional use as firewood, which involves biomass collection sites and utilization sites (corresponding to biomass production nodes and demand nodes in Figure 5-1A), modern bioenergy products can only be obtained through professional conversion processes. Thus, the third type of nodes, named "processing nodes", is to be introduced and inserted between two existing types (Figure 5-1B), which symbolizes the locations of bioenergy plants in reality. Once all the features of the processing nodes (meant to the type, production capacity and location of bioenergy plants in reality) are fixed, the scale and direction of material flows (i.e. the transportation network in the real world), including biomass feedstock flow, bioenergy products flow and bioenergy co-product flow, are simultaneously shaped between the different groups of nodes. In other words, the bioenergy plants locations can decide the pattern of bioenergy industry transportation network and vice versa.

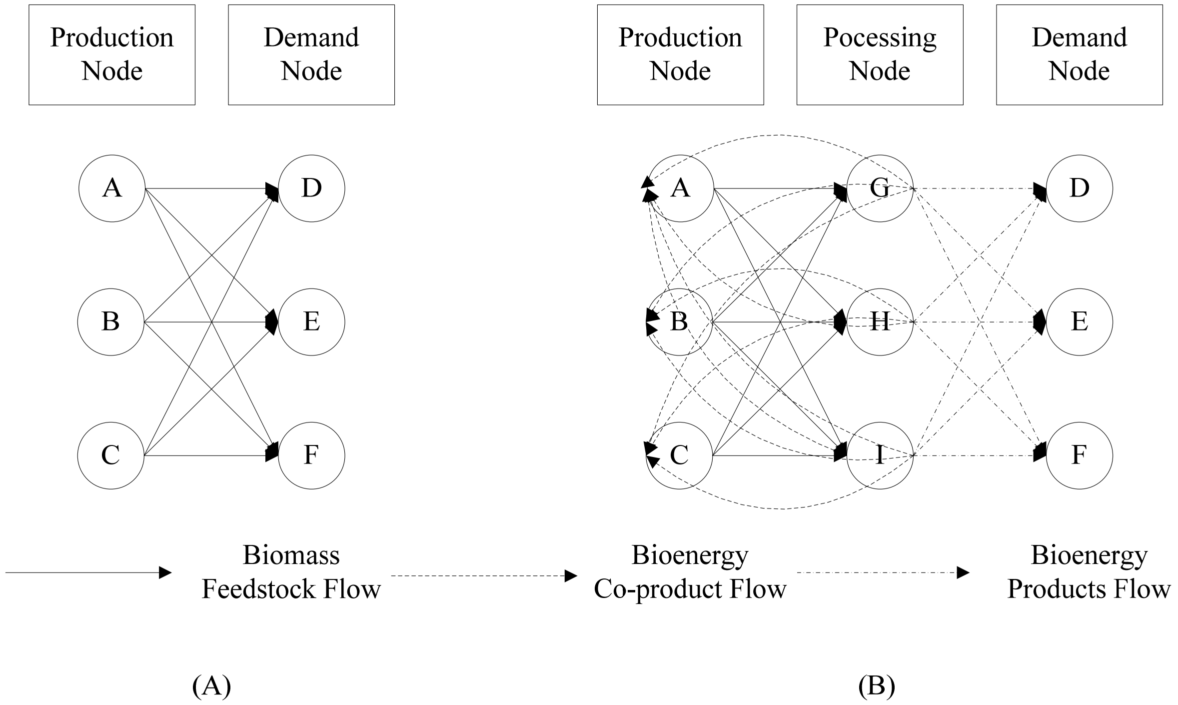


Figure 5-1 The material flows and nodes of the bioenergy industry

5.2.3 The optimal bioenergy industry infrastructure problem

Through above analysis, it is clear that the optimal bioenergy industry infrastructure problem can be simplified as a bioenergy plant location problem. Economically, the latter problem can be formulated as searching for a trade-off between the economies of scale brought by concentrated bioenergy plants and the reduced transportation cost induced by diffuse plants.

As a classical example in the linear programming, a facility location problem has been discussed for more than half a century. At the initial stage, the models are mainly designed to solve the problems relating to the food industry. In 1976, Fuller et al. developed a technique to solve large-scale mixed-integer plant-location problems (Fuller et al., 1976). They translated the location problem into a minimum-cost-flow network problem and solved it with a special purpose network code in conjunction with implicit enumeration. Using this technique, they successfully resolved the issue of a cotton-ginning sub-industry's least-cost organizational adjustment to exogenous factors. A year later, (Hilger et al., 1977) solved a grain sub-terminal location problem within northwestern Indiana, which could also be categorized into a mixed integer program, with Benders Decomposition technology.

Along with the biomass conversion technology development, modern bioenergy utilization has gradually been a focus of researchers. English et al. (1981) introduced corn residue as an auxiliary fuel in coal-fired power plant and established a linear programming model representing Iowa's agricultural sector and biopower-producing complex to assess the economic feasibility of the biomass introduction to power industry. More recently, both the source of biomass feedstock and its utilization scale have been expanded. Besides that, the invention of a series of advanced software of linear programming has further boomed the development of bioenergy utilization. Since 2000, General Algebraic Modeling System (GAMS) was used in various studies related to biomass production problems such as Nienow et al. (2000) used GAMS to examine the cost competitiveness of plantation-produced woody biomass and waste wood in a co-firing power plant in northern Indiana. Kaylen et al. (2000) analyzed the economic feasibility of lignocellulosic bioethanol by using the same programming. Similarly GAMs with cplex solver for multi-region and multi-period was used for lignocellulosic bioethanol industry in Oklahoma, USA to establish a mixed integer mathematical programming model to obtain the most economical source of lignocellulosic biomass, appropriate time for harvest and storage, inventory management as well as the scales and locations of biorefineries (Gelson et al., 2003, Mapemba et al., 2007).

Besides of using GAMS to construct mathematical programming models, some other technologies have also been creatively adopted: For example, De La Torre Ugarte and Ray (2000) applied the framework of POLYSYS (The Policy Analysis System), a national simulation model of the US agriculture sector, to biomass and bioenergy subsector; Sokhansanj et al. (2006) developed the framework of a dynamic integrated biomass supply analysis and logistics model (IBSAL) using an object oriented high level simulation language EXTEND; Kumar et al. (2006) ranked biomass feedstock collection and transportation systems by developing a multi-criteria methodology; Eathington and Swenson (2007) proposed a GIS-based decision tool for the selection of sites, scales, and technologies of biorefineries.

Compared with other methods, the mixed-integer optimization mathematical model is a relatively advanced research method, which embodies a meaningful economic perspective. Meanwhile, GAMS is a high-level modeling system for mathematical optimization, tailored for complex, large-scale modeling applications, which is fairly flexible and easy to connect to other software. By importing the simulated result from GAMS to ArcGIS for instance, the disadvantage of GAMS on visualization can be greatly compensated by ArcGIS powerful capability of geographic displays. Based on study objectives and pros and cons of various programming tools, we preferred to adopt the combination of both software (GAMs and ArcGIS) to execute the construction and demonstration of our optimizing model of bioenergy industry infrastructure.

Following our previous research on optimizing the biomass feedstock provision in the Jiangsu province in Chapter 4, the transportation network together with facility locations is simulated in this new model. Different from above existing models which only focused on single bioenergy plant (either power plant or bio-refinery), this study covers both kinds of bioenergy plants. Furthermore, since bioslurry is suggested to be used as an organic fertilizer to crop cultivation, its delivery back to biomass source regions is also involved in this model. To sum up, the conceptual framework of our model is showed in Figure 5-2.

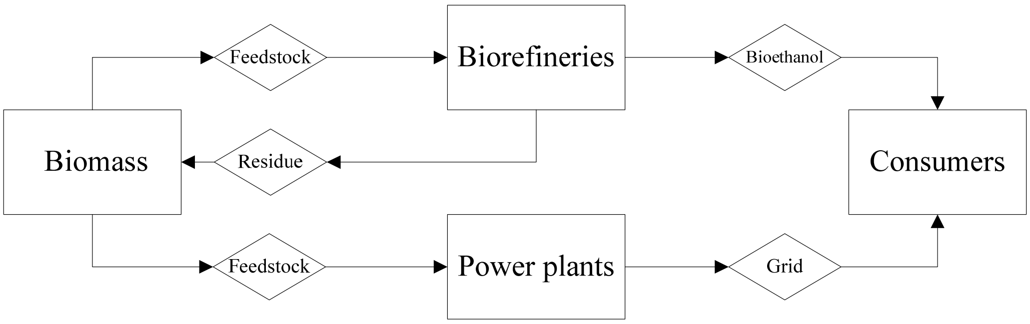


Figure 5-2 The framework of bioenergy industry infrastructure model

5.3 The optimization model of bioenergy industry infrastructure in the Jiangsu Province

5.3.1 The structure of the spatial-agent dynamic model

Different from most existing studies in solving bioenergy plant location problem, which minimize the cost of all infrastructures of the bioenergy supply chain, our optimization model depicts the total benefit of the supply chain, implying that the benefit from bioenergy products selling is also covered. Thus, the optimization direction of our model is to maximize the total benefit. The advantage of this processing method is to integrate the bioenergy products demand curves into our model, so as to enable our model, as a simulation tool, to quantitatively assess the effects of various policies from the perspective of welfare economics.

Although the application of bioenergy in China includes biological chemical transition (biogas and fuel alcohol), biomass gasification (power generation or thermal power coproduction), biomass liquefaction (biodiesel) and direct burning (boiler burning, dense burning and garbage burning) (China National Development and Reform Commission (CNDRC), 2012), only two bioenergy products (lignocellulosic biofuel and direct burning-generated power) are covered by our model in light of their current and envisioned shares in the local bioenergy market of Jiangsu province. The by-product of biofuel, bioslurry, is arranged to be sold as an organic fertilizer on farms, bringing extra benefits to the bioenergy plants. Therefore, the total revenue of the model comes from three sources- two bioenergy products, one by-product and governmental financial support. As to the cost part, capital cost, operating cost, feedstock cost and transportation cost are all taken into consideration. The total benefit, formulated as the objective function of the model, is retrieved by subtracting the total cost from the total revenue.

Besides of the objective function, a group of constraint equations consists of another indispensible component of programming models, which specifically regulate the physical, technical or other artificial conditions the model has to meet. In terms of decision variables, they are the simulation targets of models and mathematically their optimal solutions can warrant the objective function to reach its extreme value and, in the meantime, meet all the requirements set by the constraints. In our model the sizes and locations of bioenergy plants and the amount and direction of transport flows are included in this category. Table 5-1 interprets the meaning of these constraints and decision variables occurred in our model. For more details, the mathematic expressions attached to this chapter can be referred to.

5.3.2 Model parameterization

5.3.2.1 Biomass feedstock provision

A key data set needed in our optimization model of bioenergy industry infrastructure is the spatial and temporal distribution of biomass feedstock provision, i.e., the annual output of biomass feedstock in each county. As these projected data cannot be directly collected from reality, we have developed a biomass provision model to simulate the optimal biomass feedstock supply in the Jiangsu province ahead of this research. The results of biomass provision simulation are, therefore, introduced into the current model and used as an exogenous parameter. For simplicity, all different kinds of biomass feedstock are treated indifferently in our model with respect to their ash content, moisture, heat value, the content of lignocellulosic, structure, chemical composition and other features. Therefore, they share exactly the same combustion and refinement characteristics, one reason being that the large-scale differentiated performance data for each kind of biomass feedstock is inaccessible in the Jiangsu province.

Table 5-1 The overview of model constraints and decision variables

Model components	Items	Interpretation
Constraints	Total feedstock supply	The annual amount of biomass feedstock provision for bioenergy products production in each county is exogenously given.
	Bioenergy products conversion	In the current technical conditions, the ideal conversion ratios of biomass feedstock to bioenergy products are fixed.
	Bioenergy plants capacity limitation	Techno-economically, the maximum installed capacity of each single bioenergy plant as well as their minimum utilization efficiency is fixed. In addition, the maximum service life of installed devices is set at 15-year.
	Bioenergy products production	The possible output of bioenergy products in each plant is capped by the maximum production capacity of that plant.
	Bioenergy products demand	The output of bioenergy products or by-products should meet their demands in each county.
	Bioethanol and bioslurry balance	As bioslurry is a by-product of bioethanol, there is an unchangeable proportion between these two products.
Decision variables	The sizes and locations of bioenergy plants	These variables can specifically demonstrate for each county which type of bioenergy plants is installed at which level of production capacity in each year across the whole model timeframe.
	The transport amounts and directions of biomass feedstocks	This group of variables gives the information about how many biomass feedstocks should be transported from which biomass source region to which bioenergy plant in every year during 2011-2030.
	The transport amounts and directions of bioenergy products (byproducts)	They tell us which kind of bioenergy products should be transported from which bioenergy plant to which county at which amount in every year throughout the whole projected time.

5.3.2.2 The construction of transportation network

For qualified candidates for bioenergy plants allocation, two vital conditions need to be met: an easy access to the local transportation network and the availability of sufficient water resource for bioenergy products producing. Since every county in the Jiangsu province is connected through an advanced road system and accessible to rich water resource, the whole Jiangsu province is suitable for accommodating bioenergy plants.

In terms of the modes of freight transport, globally, mainly railways, trucks, ships and pipelines are used as the means of the biomass transportation. Some studies have compared the cost between different ways of transshipment based on the practical data collected in the US and UK, and calculated the minimum economical shipping distance of each mode (Bonilla and Whittaker, 2009, Mahmudi and Flynn, 2006). Due to the highly advanced road networks and short shipping distances within the province, trucks are the common mean of biomass transportation in the Jiangsu Province. For this reason, we only consider this freight transport mode in this model.

As an approximation, the whole area of each county is contracted to a point, the centroid of that county, and this point is treated both as an origin and destination for across-county freight shipping. In reality, the position of the centroid is equalized as the place where the county's administrative authorities locate. The distance between each pair of centroids can be collected from the official website of Bureau of Transportation of the Jiangsu province.

5.3.2.3 Cost structure of bioenergy plants

The total cost of running a bioenergy plant is composed by three main components (Kang, Önal, 2010): (i) annualized fixed cost, which includes the cost of land for bioenergy plants' physical structure (calculated on the basis of the rent of arable land and the size of occupied land), and the one-off investment on factory buildings and machinery; (ii) processing cost, which is proportional to the production capacity utilized (which can be assessed by the amount of biomass feedstock processed); and (iii) other costs related to operational expenses, such as labor and administrative expenses, which are linked to the installed capacity of plants.

Through reviewing the academic literatures taking China as the case region, we adopt the following values listed in Table 5-2 for their corresponding parameters.

5.3.2.4 Bioenergy products demand

The level of bioenergy products demand in our model is mainly set in accordance with the officially proposed development goals of biofuel and biomass-based power. However, to introduce the values into the optimization model, there are still two more problems to address:

(1) how to translate the targets in the five-year plan into the annual targeted value across the whole time horizon; (2) how to break down the projected annual target on the provincial level into the county-level.

Table 5-2 The cost structures of bioenergy plants used in the model

Cost structure Type of plant	Unit	Annualized fixed cost	Feedstock cost	Operational cost	Total	Data source
Biorefinery	10^3CNY/tonne	0.249	6.160	1.461	7.870	Jiang, Sun, 2012b
Power plant[1]	10^3CNY/MW	713	0.459	383.360	0.602[2]	Zhang, Zhang, 2012

Notes: 1. The preliminary cost data of operating power plant is excerpted from an internal report distributed on the "Biomass power plant Forum" hosted by Jiangsu Electric Power Industry Association in February, 2012.

2. The unit cost of power generation is calculated in the assumption that annual utilization hours of installed turbine are 7650 hours. In reality, due to the seasonal supply of biomass feedstock and equipment maintenance, the ideal utilization hours are hardly to be reached. In this case, the unit cost in reality should be higher than the 0.602 CNY/kwh and usually fluctuates around 0.8 CNY/kWh.

In order to answer the first question, we adopt the regression analysis to analyze the original data. To be more specific, as the historical data about bioenergy products is available, we can combine their historical output and projected targets and set up a regression equation to interpolate the unknown values in the gap years. As to the by-product of biofuel, i.e. bioslurry, which is not included in the official development plan, we just hold the fixed proportional relationship between biofuel and bioslurry throughout the whole timeframe. Accordingly, the bioslurry demand can be confirmed, once the biofuel demand is projected.

With regard to the second question, we apply different strategies to different bioenergy products and by-product. Firstly, let us take the demand of biomass-based power as an example to demonstrate the strategy. We collect historical data of each county's power consumption from the statistical year book of Jiangsu province (2002-2011) and perform regression analysis which is further used to predict future total power demand of each county. The predicted power demand is the total amount of power, which includes not only biomass-based power, but also other sources of power. Then we sum up the county-level power demands to the annually provincial power demand. Using this provincial amount as a reference, we can normalize each county's total power demand and finally obtain the share of each county's power demand to the provincial demand. This share is then used as a reference ratio to decompose the annual target of biomass-based power on the provincial level achieved in the first step into the county-level. Meanwhile, as the consumption data of motor gasoline in the Jiangsu province is inaccessible, we have to use the above ratio to decompose the annual biofuel target. As to the bioslurry target disintegration, we take the share of each county's biomass output to the provincial output as the distribution ratio.

5.4 Simulation result

5.4.1 The spatial distribution of bioenergy plants and their scales

(1) The spatial distribution of bioenergy feedstock provision

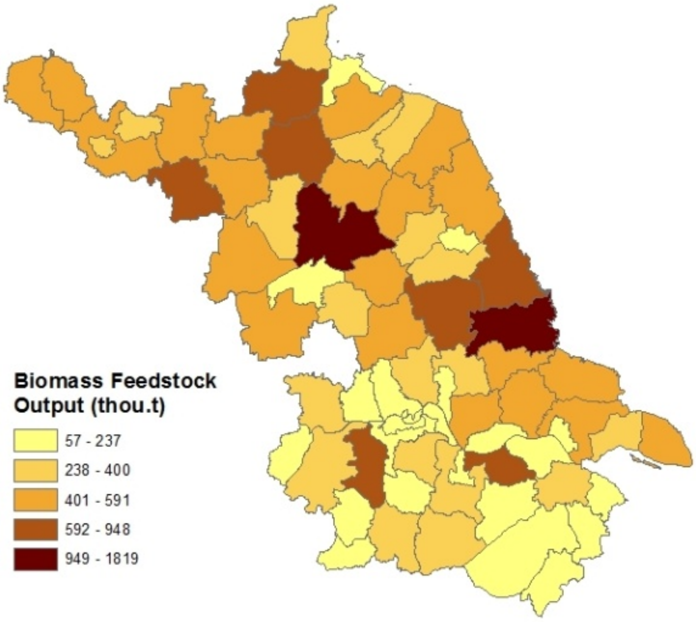


Figure 5-3 The projected distribution of biomass feedstock output in Jiangsu province in 2030

Figure 5-3 shows the projected distribution of biomass feedstock provision in 2030. We assume that biomass feedstock provision comes from two sources - either from the straws of conventional crops or from energy crops. Specifically this study covered the cultivation of seven conventional crops (wheat, oilseed rape, medium-indiea-rice, non-glutinous-rice, corn, cotton and beans) and four energy crops (switchgrass, silverreed, giantreed and miscanthus). As shown in Figure 5-3, the source of biomass output in the Jiangsu province generally follows the principle of high output in the north and low in the south, with a tremendous gap between the counties. For example, the highest output recorded in Dongtai city (1 818.89 thousand tonnes) is 32 times as much as the lowest output in Zhenjiang city (56.89 thousand tonnes). In terms of regional difference, the southern Jiangsu, owning an advanced secondary and tertiary industry and dense population, has a higher demand of energy. Therefore, given an obviously spatial disparity between biomass output and bioenergy demand, our research on optimizing the distribution of bioenergy plants and the related transportation network makes sense.

(2) The distribution of biorefineries

In order to intuitively present the simulation result of the layout of biorefineries, we use ArcGIS 10.2 platform's function of classification and symbolized display to visualize our numerical results. As we mentioned before, the classical facility location problem of bioenergy plants can be translated into a question of how to allocate a plant (i.e. "processing node" in our paper) between biomass feedstock supply region (i.e. "production node") and bioenergy products consumption center (i.e. "the demand node"). To answer this question, we project the distribution of biorefineries (the spots in Figure 5-4) on the layers of taking either the production nodes (the polygons in Figure 5-4A) or the demand nodes (the polygons in Figure 5-4B) and explore the correlations between the spots and the polygons. What we need to notice is that the biomass output data and bioenergy products data have been converted from absolute value into intensity so as to rule out the impact of county size.

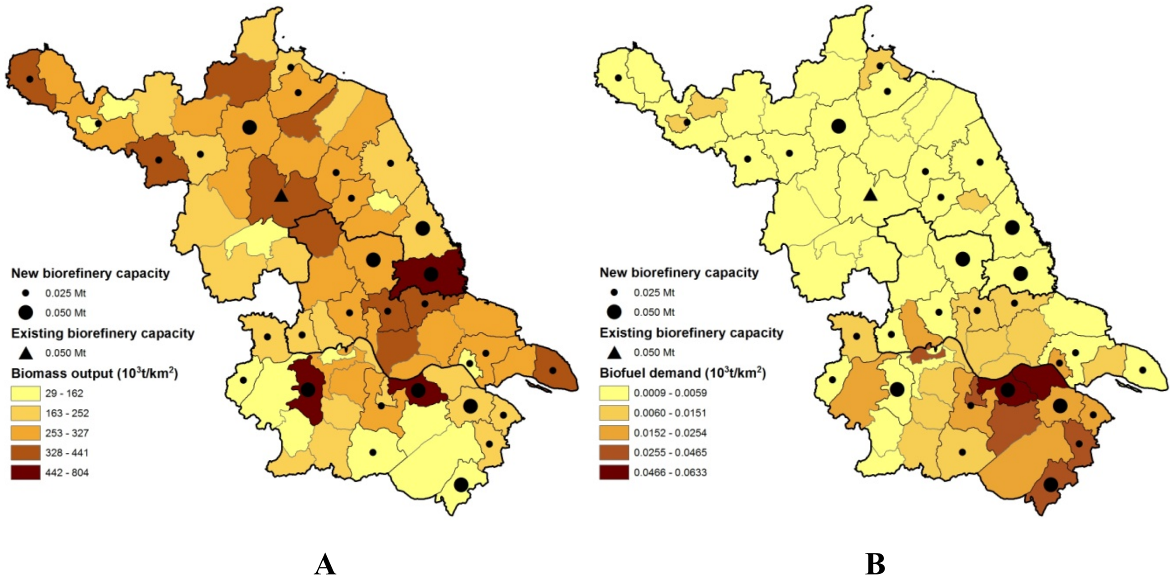
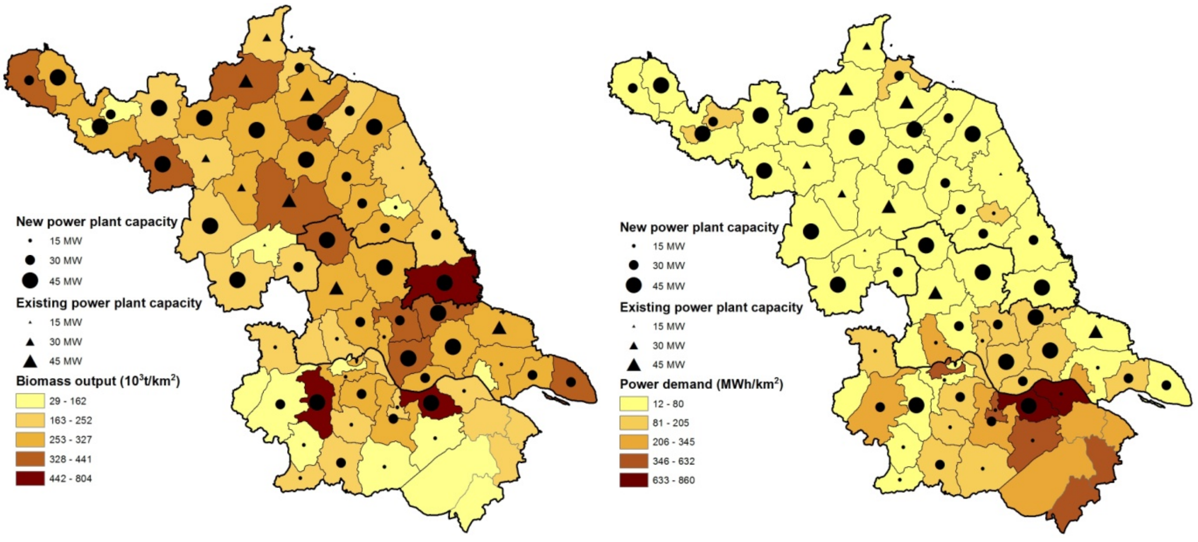


Figure 5-4 The projected distribution and scale of biorefineries in Jiangsu province on the layer of (A) production nodes and (B) the demand nodes in 2030

According to Figure 5-4, the distribution of projected biorefineries in the Jiangsu province generally concentrates in three areas: In northern Jiangsu, the biorefineries are located along the axis stretching from northwest to southeast (especially, the axis consists of Fengxian-Tongshan- Suining- Suqian- Shuyang- Huai'an- Funing- Jianhu- Sheyang- Dafeng- Dongtai), whereas in central and southern Jiangsu, the counties the Yangtze river flows through as well as the ones surrounding the Shanghai city are favorable candidates. The only existing biorefinery located in huai’an county will be kept in 2030 and its scale will be retained at the current level.

As to the scale of single biorefinery, a techno-economic analysis of cellulosic ethanol fuel production (Zheng, 2011) recommends to fix the maximum allowance level of installed capacity for a single biorefinery at 0.05 Mt. Furthermore, in view of the local demonstrative plant, biorefineries with two scales are introduced, i.e. 0.025 Mt and 0.05 Mt. Among the total 31 biorefineries projected in 2030, 9 plants will equip the highest installed capacity, with other 22 plants each owning the capacity of 0.025 Mt. For the large scale biorefineries, 8 plants will be equally partitioned into both northern and southern Jiangsu, with one plant allocated in the central part. Because of the reasonable setting of biorefinery's scale, the production capacity in each projected biorefinery is fully exploited in the optimizing model. Comparing the consistency of spatial distribution of spots and polygons within two figures, Figure 5-4 (A) has a better uniform shape, implying that biorefineries are located more closely to biomass feedstock source regions rather than to bioethanol consumption centers. The reason to this phenomenon is the relatively costly transportation of biomass feedstock from source regions to biorefineries and bioslurry from biorefineries back to biomass source regions, compared to the delivery of bioethanol from biorefineries to bioethanol consumption centers (the transportation cost of biomass feedstock and bioslurry in total is 1.922 CNY/t.km and the cost of bioethanol is 0.708 CNY/t.km). Although this theory can explain the allocation of most biorefineries, there are several counties exceptionally located in the counties neighboring to the Shanghai city. The high demand for bioethanol there successfully outweighs its disadvantage of relatively scarce biomass output and thus, becomes the decisive factor to determine the biorefineries allocation.

(3) The distribution of power plants



A **B**

Figure 5-5 The projected distribution of power plants in Jiangsu province on the layer of (A) production nodes and (B) the demand nodes in 2030

Totally, 60 biomass-fired power plants are projected to be set up in 2030. Among those, all the currently existing plants will be preserved and almost every county is designed to build up a power plant on its soil. But for the location of large-scale power plants, a similar distribution principle to biorefineries can be seen: the northwest-southeast axis in northern Jiangsu and the belt along the Yangtze River across central and southern Jiangsu are maintained. The only difference lies in the absence of counties surrounding the Shanghai city.

In terms of power plants' scales, three level scales are adopted- 15 MW, 30 MW and 45 MW- and the maximum allowance value of installed capacity for a single power plant is fixed at 45 MW. In such a flexible system of power plants' scales, the utilization ratio of each plant is to reach 100% in 2030. The distribution of power plants has been listed in details in Table 5-3.

Table 5-3 The projected sub-regionally differentiated distribution of power plants with a three-level scale in Jiangsu province in 2030

Scales	Existing power plants			New power plants			Total
15MW	2			24			26
	Nor:2	Cen:-	Sou:-	Nor: 6	Cen:7	Sou:11	
30MW	3			13			16
	Nor:3	Cen:-	Sou:-	Nor: 8	Cen:3	Sou:2	
45MW	5			13			18
	Nor:3	Cen:2	Sou:-	Nor: 8	Cen:3	Sou:2	

Note: the symbols of "nor", "cen" and "sou" represent for northern Jiangsu, central Jiangsu and southern Jiangsu respectively.

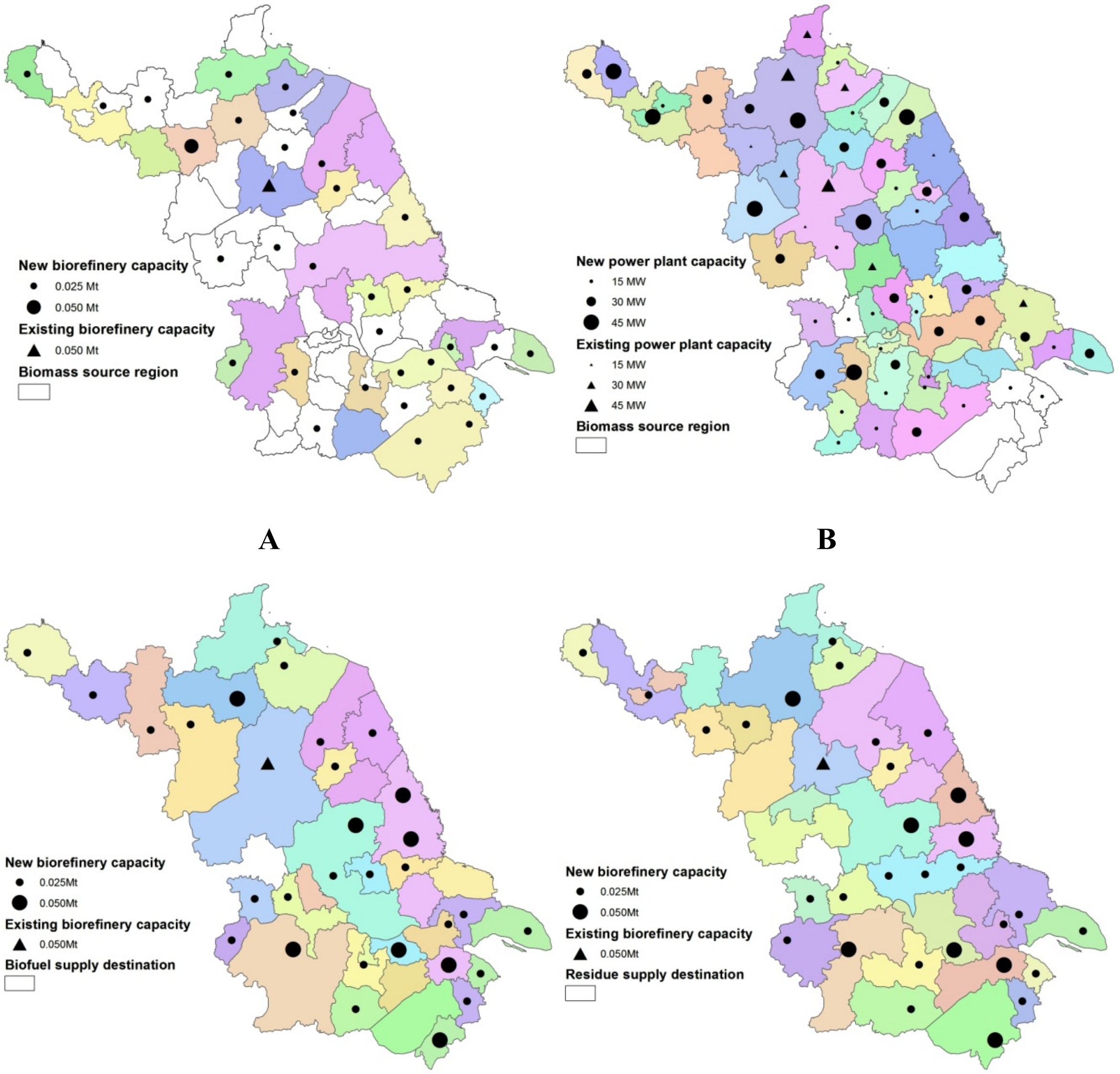
As shown clearly in the above figure, the northern Jiangsu has been projected to accommodate large scale biomass-fired power plants (on the level of 45MW, 11 out of 18 plants are located in northern Jiangsu and on the level of 30MW, this share rises up to 69%). Among 10 existing power plants, compared to their current production capabilities, the scale of six plants is to be improved, with another two to be the same and the last two to be contracted in 2030, which, above all, is generally consistent with the increasing tendency of power demand.

To the facility location problem, the distribution of biomass power plants shares the same characteristic as biorefineries, also closing to the biomass source regions. The reason is straightforward: biomass-based power, in the model, is designed to be integrated into grid. Therefore, the delivery of biomass feedstock is the only source of transportation cost and becomes the exclusive factor to determine the sites of biomass-fired power plants.

Now we take the two kinds of bioenergy plants as a whole to consider the bioenergy projects implication in the Jiangsu province. Six counties, named "promising sites" for bioenergy plants allocation can be picked out among 70 candidates (northern Jiangsu: Shuyang, Huai’an and Dongtai county; central Jiangsu: Xinghua county; southern Jiangsu: Jurong and Jiangyin county). In our simulation, they accommodate both biorefineries and power plants with the largest scale and simultaneously rank among the top areas of biomass output. This overlap, to some degree, can be regarded as a proof for supporting our previous judgment that the main factor to determine the allocation of bioenergy plants is the pattern of biomass output rather than bioenergy products demand. Among three sub-regions, the performance of northern Jiangsu is more outstanding, in which up to 44% of new biorefineries and 62% of power plants with the largest scale are projected to be located. In this sense, the official orientation of northern Jiangsu as a modern bioenergy production base is confirmed by our model.

5.4.2 The transportation of bioenergy

In this section, our research focus moves on to the other pillar of the bioenergy infrastructure-the transportation network. In Figure 5-6, we delineate the projected transportation network of bioenergy industry in 2030. The first two pictures deal with the transportation of biomass feedstock, with Figure 5-6 (A) representing the delivery of biomass feedstock from supply areas to biorefineries and 5-5-6 (B) depicting the biomass source regions for each power plant. From the distribution of blank areas in both graphs - denoting no biomass supply for the corresponding type of bioenergy plant, a mutual exclusion of those areas in two plots can be observed, which is meant to be a highly coordinated distribution of two kinds of bioenergy plants. In the meantime, as disclosed by the simulation result, for the biomass source regions producing limited biomass feedstock, the highly specific biomass supply to only one kind of bioenergy plants rather than a mixed supply is more profitable.



A B

C D

Figure 5-6 The projected transportation network of (A) biomass from supply bases to biorefineries (B) biomass from supply bases to power plants (C) biofuel from biorefineries to consumption centers and (D) bioslurry from biorefineries back to biomass supply bases in Jiangsu province in 2030

Notes: The polygons with different colors are used to distinguish the biomass source region (or supply destination) for each bioenergy plant from the others. Specifically, the counties having the same color offer biomass foodstock to the same bioenergy plant (Figure 5-6 A and B) or they are the supply destination of bioenergy products from the same bioenergy plant (Figure 5-6 C and D).

Figure 5-6 (C) and (D) demonstrate the dissemination of product and by-product of biorefineries. Despite sharing the same production pattern, the dispatch of biofuel and bioslurry is fairly different, due to their spatially differentiated demand. As shown in Figure 5-6 (C), the polygons with smaller scale in southern Jiangsu, symbolizing a shorter transportation distance of bioethanol than in the northern part, is the reflection of the northern part's weak bioethanol demand. That is to say, the output from a biorefinery in the northern part can cover a larger area than the one with the same production capacity in the south. Instead, the delivery of bioslurry performs more actively in northern Jiangsu, the main biomass source regions, which demand for a large amount of bioslurry as fertilizer.

In addition, the smaller polygons in Figure 5-6 (A) and (B) than the ones in 5-6 (C) and (D) clearly reflect the fact that the scale of biomass feedstock shipping is always incomparable to that of bioenergy products. Table 5-4 gives us numerical evidences to support the above judgement.

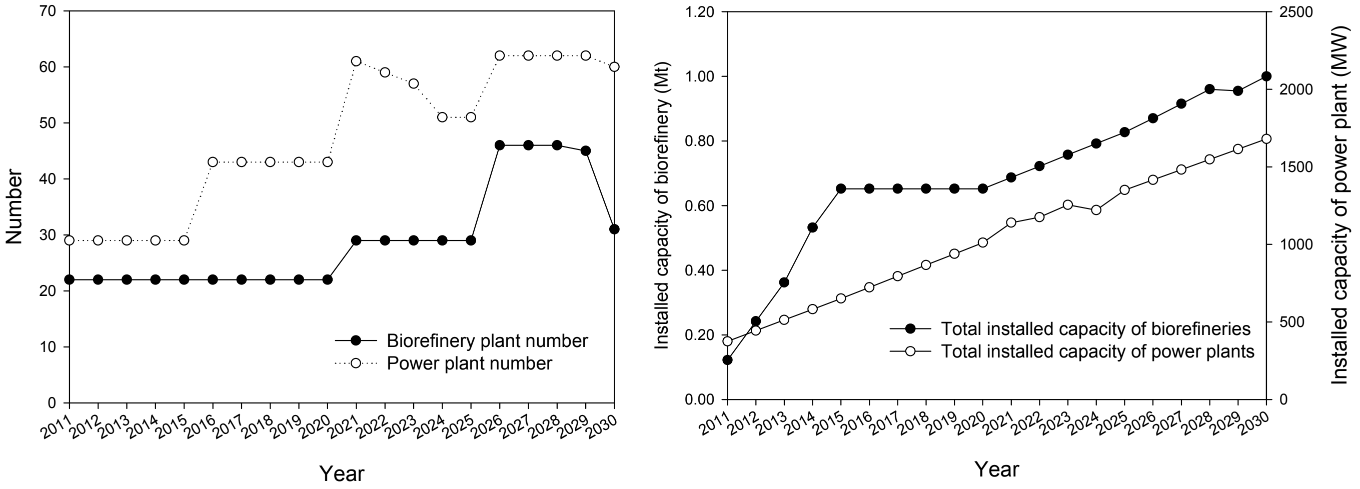
Table 5-4 The statistic indices of projected four cross-county transportation routes in Jiangsu province in 2030

Transportation routes / Statistic indices of cross-county transportation	Biomass feedstock (to biorefineries)	Biomass feedstock (to power plant)	Biofuel (to consumption center)	Bioslurry (to biomass supply bases)
The shortest distance (km)	16	10	11	11
The longest distance (km)	59	86	243	187
The average distance (km)	36.40	41.19	71.66	60.40
The transportation frequency	15	32	65	67

By comparing the first two columns with the last two, the same conclusion can be drawn. This result unambiguously proves our prior judgement that the bioenergy plants are planned to be located more closely to biomass feedstock source regions.

Additionally, another heterogeneity lying between biorefineries and biomass-fired power plants can be sorted out. The phenomenon that the majority values listed in column 1 are smaller than the ones in column 2 demonstrates that the biorefineries are allocated preferentially by the optimizing model.

5.4.3 The comparison of two biomass utilization methods: power and biofuel



A **B**

Figure 5-7 The projected number (A) and total installed capacity (B) of two types of bioenergy plants in Jiangsu province between 2011-2030

After respectively discussed the site and scale of two kinds of bioenergy plants as well as their related transportation networks in 2030, we are now examining their performances across the whole projected period. In Figure 5-7, both the (A) number and (B) total installed capacity of two kinds of bioenergy plants are exhibited.

In general, along with the booming demand for bioenergy products, the number and installed capacity of both kinds of bioenergy plants are increasing. Meanwhile, the ladder-like growth pattern can also be observed in Figure 5-7 (A), which is believed to be the result of our assumption that the phasing in or phasing out process of a single bioenergy plant lasts for five years and correspondingly, the production capacity of such a plant increases or decreases annually by 20%. In addition, a sudden drop in the number but continuously rising momentum in installed capacity manifest the concentration process of biorefineries in 2030.

In terms of the utilization scales of two kinds of bioenergy products, biomass-based power dominates Jiangsu's bioenergy market for the whole time. Its leading role in the bioenergy market is a comprehensive consequence led by both a favored development strategy to power and technical obstacles in bioethanol production from lignocellulosic biomass. However, once the obstacles, in the long term, are overcome, biorefineries' installed capacity is expected to extend 8 times in just two decades, with their counterparts- biomass-fired power plants- enlarging 4 times in the same period.

5.4.4 The introduction of pretreatment of biomass feedstock

As Richard (2010) has stressed that the soaring transport volumes inflamed by the rapid growth in demand for lignocellulosic bioenergy are likely to exceed the combined capacity of grain, petroleum and coal supply chains, he suggests taking the methods of satellite preprocessing and densification for long-distance transport. Therefore, in this section we focus on the biomass feedstock densification process and quantitatively assess its impact on the transportation network with conducting an economic accounting of bioenergy plants by using our model. Initially, we suppose all biomass source regions are obliged to install densification facilities. The additional preprocessing cost led by the new devices is set at 85 CNY/tonne and correspondingly, the transportation cost of packed biomass reduces to 0.5 CNY /tonne.km in our model (Qi, 2007).

Table 5-5 Statistic indices of the cross-county part of projected four transportation paths with the introduction of biomass feedstock densification in Jiangsu province in 2030

Transportation path / Statistic indices of cross-county transportation	Biomass feedstock (to biorefineries)	Biomass feedstock (to power plant)	Biofuel (to consumption center)	Bioslurry (to biomass supply bases)
The shortest distance (km)	12	10	11	11
The longest distance (km)	63	103	261	201
The average distance (km)	36.50	41.11	79.63	65.49
The transportation frequency	14	19	70	69

Comparing Table 5-5 with Table 5-4, the biomass feedstock densification obviously has a positive impact on the long-distance biomass transportation, which can be proved by the increased longest distances of biomass feedstock delivery for biorefineries and power plants. Meanwhile, the densification process prompts the expansion of bioenergy products' transportation network, which, however, seemly contradicts to our intuitive perception that the cut transportation cost of feedstock should help relax the constraint of biomass processing facilities located closely to the biomass source regions. We argue that this simulation result is partly due to the extra preprocessing cost. In other words, the newly introduced preprocessing cost is expected to weaken the role of lower transportation cost on improving the distribution flexibility of bioenergy plants. As illustrated in Table 5-6, the plants' expenditures on fuel cost have, instead, risen. Such mechanism forces the bioenergy plants to be relocated close to the biomass source regions even further when the biomass densification process introduces.

Table 5-6 The projected economic accounting with/ without biomass feedstock densification between 2011-2030 (10^6 CNY)

Bioenergy plants type / Cost and revenue		Without densification		With densification	
		Biorefinery	Power plant	Biorefinery	Power plant
Cost	Biomass densification	-	-	0.288	0.927
	Biomass transportation	0.156	1.218	0.063	0.305
	Bioenergy plants operation	57.814	50.146	56.315	49.896
	Bioenergy products delivery	0.603	-	0.559	-
Revenue	Bioenergy products selling	112.866	88.487	111.421	87.59
Net benefit		**54.293**	**37.123**	**54.196**	**36.462**

Besides that, the added fuel cost renders the production capacities of two kinds of bioenergy plants shrinking and leads to a net benefit loss at 0.758×10^6 CNY. Based on this calculation result, we suggest that the compulsory introduction of biomass feedstock densification process to the Jiangsu province is not economically desirable for the bioenergy industry. Since the newly introduced preprocessing cost cannot be fully compensated by the saved transportation cost under the circumstance of limited scale of transportation network within Jiangsu, a broader transportation network, for example the one throughout China, perhaps can refute our previous judgement. In addition, it is worth noting that this conclusion is made only for the bioenergy industry. If the positive social effects of densification process, i.e. the less turbulence on the delivery of other commercial goods, e.g. grain, petroleum and coal, are taken into consideration, a different picture could probably be seen.

To verify our judgment, we alternatively adopt a spontaneous decision process, in which bioenergy plants operators can decide on their own whether or not to install such densification facilities. Not surprisingly, no operators in the new scenario are willing to adopt these devices when only their own benefits are counted. This implies that in a bid to rectify the positive externality of biomass pretreatment process on other related industries as well as local transportation system, the subsidy from governments is necessary.

5.4.5 Regional development policy

As the role of bioenergy industry on prompting regional development has been much appreciated by many bioenergy researchers (eg. Li and Wang, 2008, Thornley, Rogers, 2008), our study has designed a policy scenario of allocating at least 50% of the total production capacity of bioenergy products to northern Jiangsu, in a bid to balance the regional disparity between this region and southern Jiangsu.

Correspondingly, in order to properly facilitate the concentration of bioenergy plants in the northern area, the maximum allowable value of installed capacity for single plant in this scenario has been relaxed from 45 MW to 60 MW for bioenergy plants and from 0.05 million tonnes to 0.075 million tonnes for biorefineries. The updated distributing profiles of bioenergy plants are presented in Figure 5-8.

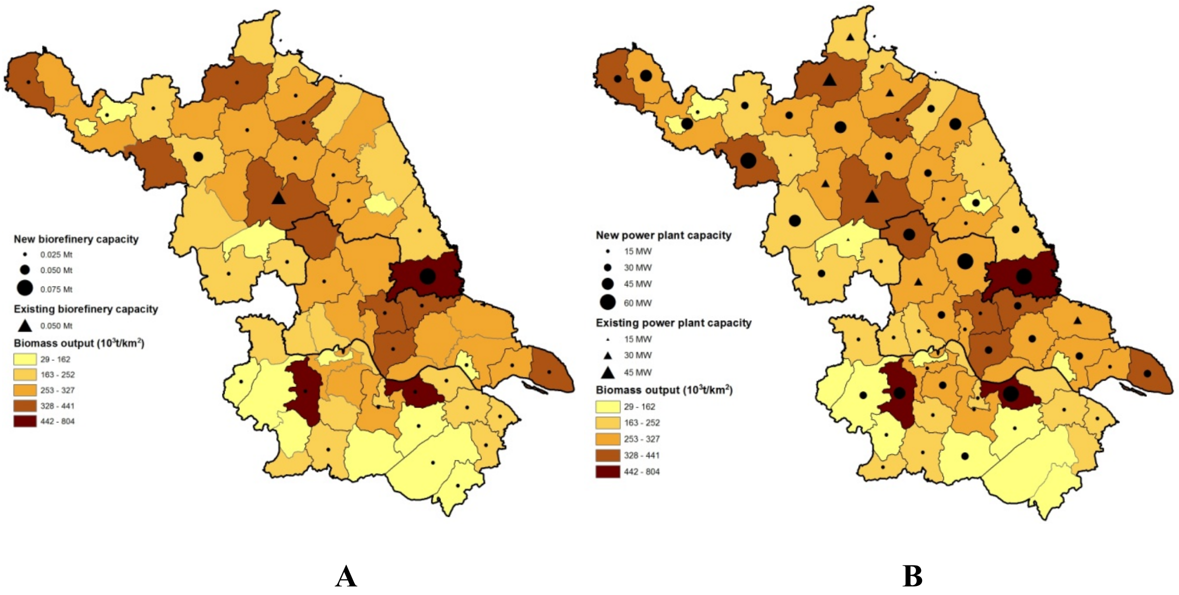


Figure 5-8 The layout of (A) biorefineries and (B) biomass-fired power plants in Jiangsu province in 2030 under the regional development policy of allocating 50% installed capacity of bioenergy plants to Northern Jiangsu

From Figure 5-8, two new features in the updated spatial distribution of bioenergy plants can be discovered: (1) the bioenergy plants are expected to be allocated in more counties, with the number of biorefineries rising from 31 to 35 and of power plants increasing from 60 to 61. (2) The favorability to bioenergy products is set to change. Compared with the basic scenario, the annual production capacity of biomass-based power will expand from 1680 MW to 1710 MW in 2030, whereas the biofuel output will shrink to 0.075 Mt from 1 Mt in the baseline. Consistent with a contracted production capacity, the shadow price of biofuel will rise by 343 CNY/tonne. Meanwhile, the shadow price of power will decrease by 0.011 CNY/kwh, thanks to the enlarged installed capacity of power plants.

On the sub-region level, more small scale biorefineries (0.025 Mt) are suggested to be introduced to the counties in the northern Jiangsu, for instance the Xinyi, Donghai, Lianshui, Xuyi and Jinhu counties. Besides that, the only largest scale biorefinery in our case (0.075 Mt) is also planned to be allocated in Dongtai county, belonging to the northern part. In southern Jiangsu, all the biorefineries are set to be at small scale. After above adjustment, northern Jiangsu gains an extra 0.075 Mt production capacity of bioethanol, with the southern and central parts losing 0.05 Mt respectively. For biomass-fired power plants, as their distributions in the baseline have already fitted to the proportion requirement, there is no additional production capacity arranged in northern Jiangsu. Oppositely, its regional installed capacity is to decrease 15 MW, although two largest scale ones (60 MW) are expected to be located in this area. The southern Jiangsu, instead, benefits from such an alteration, obtaining additional 45 MW production capacity.

5.5 Conclusions and discussion

By building up an optimizing model of bioenergy infrastructure in the Jiangsu province, we have quantitatively assessed two elements composing the bioenergy industry infrastructure: the distribution of bioenergy plants and their related transportation networks.

With regard to the first element, the distribution of bioenergy plants has shown the feature of concentration to some degree. On the sub-region level, the bioenergy plants in northern Jiangsu are optimally located along the axis stretching from northwest to southeast, while in central and southern Jiangsu, the counties the Yangtze River flows through are favorable. Additionally, the counties surrounding Shanghai city are suitable for biorefineries but not power plants. According to our simulation result, up to 44% of new biorefineries and 62% of power plants with the largest scale are projected to be located in the northern Jiangsu, corroborating evidence for the regions' official orientation as a renewable energy production basis. On the county level, thanks to their abundant biomass feedstock supply, six counties including Shuyang, Huai’an, Dongtai, Xinghua, Jurong and Jiangyin can accommodate both biorefineries and power plants with the biggest installed capacity, and thus be confirmed as the most promising places for bioenergy plants allocation. To the classical facility location problem, our model's answer is that the factor of biomass feedstock supply rather than the bioenergy products demand predominately determines the locations of bioenergy plants. The reason is that the delivery of biomass feedstock costs more than of bioenergy products.

In terms of the second element, biorefineries are given a higher priority by the model when it optimizes the transportation network. This judgement is concluded from the simulation result of a smaller scale network of biomass delivery to biorefineries than to power plants. As to the relationship between two utilization methods of lignocellulosic bioenergy, i.e. power and bioethanol, they are coordinated quite well and complementary to each other in our optimizing model. Along with the rising demand for bioenergy products, the production capacity of both bioenergy products expands, and biomass-based power dominates Jiangsu's bioenergy market in terms of its utilization scale. This trend is expected to remain in the short term. In the long term, the biorefineries can gain more market share if the technology of bioethanol production from lignocellulosic biomass can make a breakthrough.

In addition, the model unveils that the introduction of biomass feedstock densification process to the Jiangsu province does not benefit the bioenergy industry. Limited to the relatively small scale transportation network within the Jiangsu province, the newly introduced preprocessing cost cannot be fully traded-off by the saved transportation cost. Perhaps, a larger scale transportation network, for instance the one throughout China, could be favorable.

In the end, a regional development policy has been examined in our model. Under the scenario of northern Jiangsu holding 50% production capacity of bioenergy products, more counties are expected to become the candidates for bioenergy plants. For northern Jiangsu, its bioethanol production capacity will increase by 0.075 Mt in 2030, but its regional installed capacity of power plants, in the meantime, will contract by 15MW.

While offering us some insights on optimal bioenergy industry infrastructure, this model also has certain limitations: firstly, the interaction between farmers, the biomass feedstock supplier, and bioenergy plants operators, the biomass feedstock consumer, has not been sufficiently considered. For simplicity, the biomass feedstock provision is given exogenously in our model. But in local practice, the farmers can logically detect the altered biomass demand and rearrange their biomass feedstock production. Thus, in an improved model, the biomass feedstock provision should be dynamic rather than static. Besides that, only two bioenergy products have been included in our model. In view of the wide variety of biomass conversion routes, more bioenergy products should be taken into consideration.

Conclusively, despite the existence of several deficiencies, this mathematical modelling approach can still provide a valuable insight to policy makers, as well as the future investors in the bioenergy industry. Therefore, the coverage of this model is worthy of extending to other regions and finally to the whole area of China.

Appendix III The spatial-agent dynamic model specification

The general formulation of this county-level dynamic agent-based model maximizes the present value of the total profits across the whole time frame of a system covering two utilization methods of cellulosic bioenergy, subject to total feedstock supply constraints, bioenergy products conversion constraints, bioenergy plants capacity limitation constraints, bioenergy products production and bioethanol and bioslurry balance constraints.

Indices:

u: county-level regions /Nanjing, Pukou, Liuhe, Shushui, Gaochun, Wuxi, Jiangyin, Yixing, Xuzhou, Fengxian, Peixian, Tongshan, Suining, Xinyi, Pizhou, Changzhou, Wujin, Liyang, Jintan, Suzhou, Changshu, Zhangjiagang, Kunshan, Wujiang, Taicang, Nantong, Tongzhou, Hai'an, Rudong, Qidong, Rugao, Haimen, Lianyungang, Ganyu, Donghai, Guanyun, Guannan, Huai'an, Lianshui, Hongze, Xuyi, Jinhu, Yancheng, Yandu, Xiangshui, Binhai, Funing, Sheyang, Jianhu, Dongtai, Dafeng, Yangzhou, Baoying, Yizheng, Gaoyou, Jiangdu, Zhenjiang, Dantu, Danyang, Yangzhong, Jurong, Taizhou, Xinghua, Jingjiang, Taixing, Jiangyan, Suqian, Shuyang, Siyang, Sihong/

r(u): the biomass production locations /county-level regions/

j(u): candidate biorefinery locations /county-level regions/

l(u): candidate biomass-fired power plant locations /county-level regions/

n(u): the demand centers /county-level regions/

allt: time horizon /2002-2040/

t(allt): projected time horizon /2011-2040/

d：period /2011-2015，2016-2020，2021-2025，2026-2030，2031-2035，2035-2040/

goods: type of shipping goods /feedstock, bioethanol, residue/

plant: biomass utilization plant /biorefinery, powerplant/

number: the order of plants /n1-n5/

product: type of products /biopower, bioethanol, residue/

device: the type of power generation turbine /12MW, 15MW, 25MW/

turbine: the installed capacity of biorefinery /0.01 Mt, 0.02 Mt, 0.05Mt/

Exogenous data:

$c_{goods,t}$: the transportation costs by shipping per unit amount and distance for shipping goods *goods* in year *t* (10^9CNY/10^6t.km)

c^{pile} : the biomass feedstock densification process cost (10^9CNY/10^6t)

$d_{u,\tilde{u}}$: the distance between one location *u* and the other location $\tilde{u}$ (km)

$b_t^{biorefeinery}$: the annualized fixed investment cost for biorefinery plant in year *t* (10^9CNY/10^6t)

$b_t^{powerplant}$: the annualized fixed investment cost for power plant in year *t* (10^9CNY/MW)

$v_t^{biorefinery}$: the fuel cost for biorefinery plant in year *t* (10^9CNY/10^6t)

$v_t^{powerplant}$: the fuel cost for biopower generation from power plant in year *t* (10^9CNY/10^6kwh)

$o_t^{biorefinery}$: other operational costs for biorefinery plant in year *t* (10^9CNY/10^6t)

$o_t^{powerplant}$: other operational costs for power plant in year *t* (10^9CNY/MW)

$sup_{r,t}$: amount of biomass feedstock supplied by region *r*, year *t* (10^6t)

$dem_{n,t}^{bioethanol}$: demand of bioethanol in demand center *n* and year *t* (10^6t)

$dem_{n,t}^{electricity}$: demand of biopower in demand center *n* and year *t* (10^6kwh)

$dem_{r,t}^{residue}$: demand of residue in biomass production location *r* and year *t* (10^6t)

$i^{\max,biorefinery}$: maximum capacity of biorefinery plant in practical (10^6t)

$i^{\max,powerplant}$: maximum capacity of power plant in practical (MW)

$i^{\min,powerplant}$: minimum capacity of power plant in practical (MW)

$\alpha^{biorefinery}$: conversion factors from biomass to bioethanol (10^6t/10^6t)

$\alpha^{powerplant}$: conversion factors from biomass to biopower (10^6kwh/10^6t)

$\beta^{biorefinery}$: conversion factor of residue as the byproduct of bioethanol from biomass (10^6t/10^6t)

$\gamma^{biorefinery}$: the output coefficient of residue to bioethanol (10^6t/10^6t)

$\eta^{powerplant}$: the efficiency of power generation (unitless)

$\sigma^{powerplant,max}$: maximum annual utilization hours of power plant (10^3hours)

$\sigma^{powerplant,min}$: minimum annual utilization hours of power plant (10^3hours)

$\varepsilon_t^{bioethanol}$: blending rate of bioethanol into gasoline in year *t* (unitless) /E10/

$\widehat{i_{j,t}}$: newly added capacity of the existing biorefinery plant built at location *j*, year *t* (10^6t)

$\widehat{i_{l,t}}$: newly added capacity of the existing biomass-fired power plant built at location *l*, year *t* (MW)

$cap_{device}^{powerplant}$: unit capacity of each type of power generation turbine (MW)

$cap_{turbine}^{biorefinery}$: unit capacity of each type of biorefinery turbine (Mt)

lifespan: the life span of fixed equipments in biorefinery and biomass-fired power plant (years)

$ps_t^{biofuel}$: the price subsidy of per unit of biofuel in year t (10^6CNY/10^6t)

$ps_t^{residue}$: the price subsidy of per unit of residue in year t (10^6CNY/10^6t)

$ps_t^{electricity}$: the price subsidy of per unit of biopower in year t (10^6CNY/10^6kwh)

$timemapping_{t,d}$: the coefficient of accumulated installed capacity for bridging projected time horizon and period

Decision variables:

Nonnegative variables:

$Y_{r,j,t}^{feedstock}$: amount of feedstock for bioethanol manufacturing shipped from biomass production location *r* to biorefinery *j* location in year *t* (10^6t)

$Y^{bioethanol}_{j,number,n,t}$: amount of bioethanol produced by feedstock shipped from the *number* biorefinery located at *j* to demand center *n* in year *t* (10^6t)

$\widehat{Y^{bioethanol}_{j,n,t}}$: amount of bioethanol produced by feedstock shipped from existing biorefinery located at *j* to demand center *n* in year *t* (10^6t)

$Y^{residue}_{j,number,r,t}$: amount of residue generated during the processing of bioethanol production shipping from the *number* biorefinery located at *j* to biomass production location *r* in year *t* (10^6t)

$\widehat{Y^{residue}_{j,r,t}}$: amount of residue generated during the processing of bioethanol production shipping from existing biorefinery located at *j* to biomass production location *r* in year *t* (10^6t)

$Y^{feedstock}_{r,l,t}$: amount of feedstock for biopower generation shipping from biomass production location *r* to biomass-fired power plant location *l* in year *t* (10^6t)

$Y^{electricity}_{l,number,n,t}$: amount of biopower distributed from the *number* biomass-fired power plant locating at *l* to demand center location *n* in year *t* (10^6kwh)

$\widehat{Y^{electricity}_{l,n,t}}$: amount of biopower distributed from existing biomass-fired power plant locating at *l* to demand center location *n* in year *t* (10^6kwh)

$PRICE^{biofuel}_{t}$: the price per unit of biofuel in year t (10^6CNY/10^6t)

$PRICE^{residue}_{t}$: the price per unit of residue in year t (10^6CNY/10^6t)

$PRICE^{electricity}_{t}$: the price per unit of biopower in year t (10^6CNY/10^6kwh)

Integer variables:

$I_{l,number,device,d}$: number of newly equipped turbines of capacity *device* in the *number* biomass-fired power plant built at location *l*, period *d*

$I_{j,number,turbine,d}$: number of newly equipped turbines of capacity *turbine* in the *number* biorefinery built at location *j*, period *d*

Objective function:

Max WELF =

$$\sum_t (1+r)^t \bullet \left\{ \begin{array}{l} \sum_t \left[(PRICE_t^{biofuel} + ps_t^{biofuel}) \bullet \left(\sum_{j,number,n} Y_{j,number,n,t}^{bioethanol} + \sum_{j,n} \widehat{Y_{j,n,t}^{bioethanol}} \right) \right] \\ \sum_t \left[(PRICE_t^{residue} + ps_t^{residue}) \bullet \left(\sum_{j,number,n} Y_{j,number,r,t}^{residue} + \sum_{j,n} \widehat{Y_{j,r,t}^{residue}} \right) \right] \\ + \sum_t \left[(PRICE_t^{electricity} + ps_t^{electricity}) \bullet \left(\sum_{l,number,n} Y_{l,number,n,t}^{electricity} + \sum_{l,n} \widehat{Y_{l,n,t}^{electricity}} \right) \right] \end{array} \right\}$$

$$-\sum_t (1+r)^t \bullet \left\{ \begin{array}{l} \sum_{r,j} \left[\left(c_{feedstock,t} \bullet d_{r,j} + c^{pile} \$ d_{r,j} \right) \bullet Y_{r,j,t}^{feedstock} \right] \\ + \sum_{j,number} \left[\begin{array}{l} (b_t^{biorefinery} + o_t^{biorefinery}) \bullet \sum_{turbine} \left[cap_{turbine}^{biorefinery} \bullet \sum_d \left(I_{j,number,turbine,d} \cdot timemapping_{t,d} \right) \right] \\ + v_t^{biorefinery} \bullet \sum_n Y_{j,number,n,t}^{bioethanol} + \sum_n \left(c_{bioethanol,t} \bullet d_{j,n} \bullet Y_{j,number,n,t}^{bioethanol} \right) \end{array} \right] \\ + \sum_j \left[o_t^{biorefinery} \bullet \sum_{t1 \in t-14 \to t} \widehat{i_{j,t1}} + v_t^{biorefinery} \bullet \sum_n \widehat{Y_{j,n,t}^{bioethanol}} + \sum_n \left(c_{bioethanol,t} \bullet d_{j,n} \bullet \widehat{Y_{j,n,t}^{bioethanol}} \right) \right] \\ + \sum_{j,number,r} \left(c_{residue,t} \bullet d_{j,r} \bullet Y_{j,number,r,t}^{residue} \right) \\ + \sum_{j,r} \left(c_{residue,t} \bullet d_{j,r} \bullet \widehat{Y_{j,r,t}^{residue}} \right) \\ + \sum_{r,l} \left[\left(c_{feedstock,t} \bullet d_{r,l} + c^{pile} \$ d_{r,l} \right) \bullet Y_{r,l,t}^{feedstock} \right] \\ + \sum_{l,number} \left[(b_t^{powerplant} + o_t^{powerplant}) \bullet \sum_{device} \left[cap_{device}^{powerplant} \bullet \sum_d \left(I_{l,number,device,d} \bullet timemapping_{t,d} \right) \right] + v_t^{powerplant} \bullet \sum_n Y_{l,number,n,t}^{electricity} \right] \\ + \sum_l \left(o_t^{powerplant} \bullet \sum_{t1 \in allt-14 \to t} \widehat{i_{l,t1}} + v_t^{powerplant} \bullet \sum_n \widehat{Y_{l,n,t}^{electricity}} \right) \end{array} \right\} \tag{1}$$

The objective function (1) of the model maximizes the present value of the net cash flows of the production sector of bioenergy products in the Jiangsu province across the whole time frame, as the total revenue minus costs. Specifically, the revenue of bioenergy products production sectors comprises of the sale of bioethanol, bioslurry and biomass-based power, as well as the governmental subsidies. The cost mainly covers the transportation cost and preprocessing cost of biomass feedstock and the delivery cost of bioenergy products, the fuel cost, operational cost and annualized fixed cost of bioenergy plants and other auxiliary inputs.

From line 2 to line 4, the revenue terms account for:

a) the sales revenue and the governmental subsidy from bioethanol

b) the sales revenue and the governmental subsidy from bioslurry

c) the sales revenue and the governmental subsidy from biomass-based power

Starting from line 6 of the objective function, the cost items are:

d) the transportation and preprocessing cost of the part of biomass feedstock consumed in biorefineries

e) the annualized fixed cost and operational cost of newly installed biorefineries

f) the fuel cost of newly installed biorefineries and the corresponding delivery cost of bioethanol

g) the operational cost, fuel cost of existing biorefineries and the corresponding delivery cost of bioethanol

h) the delivery cost of bioslurry produced in newly installed biorefineries

i) the delivery cost of bioslurry produced in existing biorefineries

j) the transportation and preprocessing cost of the part of biomass feedstock consumed in biomass-fired power plants

k) the annualized fixed cost, the operational cost and the fuel cost of newly installed biomass-fired power plants

l) the operational cost and the fuel cost of existing biomass-fired power plants.

Subject to:

The most fundamental physical constraints on biomass feedstock provision, the installed capacity of bioenergy plants and the demand for bioenergy products.

$$\sum_j Y_{r,j,t}^{feedstock} + \sum_l Y_{r,l,t}^{feedstock} \leq sup_{r,t} \quad \forall r,t \tag{2}$$

Equation block (2) assures the amount of biomass feedstock delivered out from region r separately to biorefineries locating at j and to biomass-fired power plants locating at l cannot exceed the local biomass feedstock output in each year t.

$$\sum_{number,n} Y^{bioethanol}_{j,number,n,t} + \sum_{n} \widehat{Y^{bioethanol}_{j,n,t}} \le \sum_{r} Y^{feedstock}_{r,j,t} \bullet \alpha^{biorefinery} \quad \forall j,t \tag{3}$$

Equation block (3) guarantees that the total output of bioethanol from both newly installed and existing biorefineries cannot exceed their ideal output calculated on the basis of biomass feedstock input.

$$\sum_{number,n} Y^{electricity}_{l,number,n,t} + \sum_{n} \widehat{Y^{electricity}_{l,n,t}} \le \sum_{r} Y^{feedstock}_{r,l,t} \bullet \alpha^{power\ plant} \bullet \eta^{powerplant} \quad \forall l,t \tag{4}$$

Similarly, equation block (4) requires the total output of biomass-based power from both newly installed and existing biomass-fired power plants cannot exceed their ideal output calculated on the basis of biomass feedstock input.

$$\sum_{turbine} \left[cap^{biorefinery}_{turbine} \bullet \sum_{d} \left(I_{j,number,turbine,d} \bullet timemapping_{t,d} \right) \right] \le i^{\max,biorefinery} \quad \forall j, number, t \tag{5}$$

The aim of setting up equation block (5) is to ensure the installed capacity of each biorefinery to be lower than the technical-economically optimal capacity.

$$\sum_{device} \left[cap^{powerplant}_{device} \bullet \sum_{d} \left(I_{l,number,device,d} \bullet timemapping_{t,d} \right) \right] \le i^{\max,powerplant} \quad \forall l, number, t \tag{6}$$

Similar to the above equation block, the equation block (6) refers to power plants. It ensures the installed capacity of each biomass-fired power plant to be under the technical-economically optimal capacity.

Planned:

$$\begin{aligned} 0.5 \times \sum_{turbine} \left[cap^{biorefinery}_{turbine} \bullet \sum_{d} \left(I_{j,number,turbine,d} \cdot timemapping_{t,d} \right) \right] &\le \sum_{n} Y^{bioethanol}_{j,number,n,t} \\ \le \sum_{turbine} \left[cap^{biorefinery}_{turbine} \bullet \sum_{d} \left(I_{j,number,turbine,d} \cdot timemapping_{t,d} \right) \right] & \quad \forall j, number, t \end{aligned} \tag{7}$$

Existing:

$$0.5 \times \sum_{t1 \in t-14 \to t} \widehat{i_{j,t1}} \le \sum_{n} \widehat{Y^{bioethanol}_{j,n,t}} \le \sum_{t1 \in t-14 \to t} \widehat{i_{j,t1}} \quad \forall existing\ j,t \tag{8}$$

The group of equation block (7) and (8) is to hold the utilization ratio of production capacity for each biorefinery (Equation (7) refers to newly installed biorefineries and equation (8) regards to existing biorefineries) between 50% and 100%.

Planned:

$$\sigma^{powerplant,min} \bullet \sum_{device} \left[cap^{powerplant}_{device} \bullet \sum_{d} \left(I_{l,number,device,d} \bullet timemapping_{t,d} \right) \right] \le \sum_{n} Y^{electricity}_{l,number,n,t}$$
$$\le \sigma^{powerplant,max} \bullet \sum_{device} \left[cap^{powerplant}_{device} \bullet \sum_{d} \left(I_{l,number,device,d} \bullet timemapping_{t,d} \right) \right] \quad \forall l, number, t \tag{9}$$

Existing:

$$\sigma^{powerplant,min} \bullet \sum_{t1 \in allt-14 \to t} \widehat{i_{l,t1}} \le \sum_{n} \widehat{Y^{electricity}_{l,n,t}} \le \sigma^{powerplant,max} \bullet \sum_{t1 \in allt-14 \to t} \widehat{i_{l,t1}} \quad \forall existing\, l,t \tag{10}$$

Like the above group, this group of constraints, applying to biomass-fired power plants, is to keep the utilization ratio of each biomass-fired power plant ranging from 50% to 100%.

$$\left(\sum_{j,number} Y^{bioethanol}_{j,number,n,t} + \sum_{j} \widehat{Y^{bioethanol}_{j,n,t}} \right) / \, \varepsilon^{bioethanol}_{t} \ge dem^{bioethanol}_{n,t} \quad \forall n,t \tag{11}$$

$$\sum_{j,number} Y^{residue}_{j,number,r,t} + \sum_{j} \widehat{Y^{residue}_{j,r,t}} \ge dem^{residue}_{r,t} \quad \forall r,t \tag{12}$$

$$\sum_{l,number} Y^{electricity}_{l,number,n,t} + \sum_{l} \widehat{Y^{electricity}_{l,n,t}} \ge dem^{electricity}_{n,t} \quad \forall n,t \tag{13}$$

The group of equation block (11), (12) and (13) is bioenergy products demand constraints. These constraints require the output amount of each kind of bioenergy products (bioethanol in (11), bioslurry in (12) and biomass-based power in (13)) should at least meet its corresponding demand on the market for each region n, t and year t.

Planned:

$$\sum_{r} Y^{residue}_{j,number,r,t} = \sum_{n} Y^{bioethanol}_{j,number,n,t} \bullet \gamma^{biorefinery} \quad \forall j, number, t \tag{14}$$

Existing:

$$\sum_{r} \widehat{Y^{residue}_{j,r,t}} = \sum_{n} \widehat{Y^{bioethanol}_{j,n,t}} \bullet \gamma^{biorefinery} \quad \forall j,t \tag{15}$$

As bioslurry is the byproduct of bioethanol, the output of bioslurry in each biorefinery should be proportionate to the output of bioethanol. The equation blocks (14) and (15) are designed to reflect such principle in the model.

6 Bioenergy supportive measures and industry development: The decision support system of the bioenergy industry[1]

6.1 The current bioenergy supportive policies

The historical experiences of bioenergy growth in the EU and US unambiguously demonstrate that the development of the bioenergy industry is highly dependent on the policy support from governments. This conclusion also holds true for China. In the past twenty years, Chinese government has designed and enacted a series of laws, regulations and initiatives to promote the advancement of renewable energies. Bioenergy industry has also garnered much support. Based on policy targets and actors of the bioenergy industry, these supportive measures can be grouped into four categories: the policies for shaping a favourable external environment, for guaranteeing intermediate input, for introducing value-adding factors and for promoting bioenergy output. In the following parts, we will examine them one by one.

6.1.1 Policies for shaping a favorable external environment

Related to the promotion of renewable energy in China, the first law "*electricity law of the People's Republic of China (P.R.C.)* was introduced in 1995 followed by "*Energy conservation law of P.R.C*" (1997) and *"Air Pollution Prevention law of P.R.C*" (2000) (Peidong, Yanli, 2009). The first specific legislation on renewable energy- *"Renewable Energy Law of P.R.C"* (RELPRC) - was published in 2005 which was later amended in 2009 in order to reflect the latest progress in the renewable energy industry. In the updated version, the concept of "low-carbon" development was introduced and the supportive policies for the exploration and utilization of renewable energy, including bioenergy, were simultaneously proposed. Although lacking of specific application procedures to warrant its implication, this law, as an overarching legislation, has confirmed the status of renewable energy in the state energy-mix and shaped an institutional framework for all subordinate supportive policies. Following that, *"The 12th Five-year Development Plan of Bioenergy"* regulated the main

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[1] This chapter is to be submitted to the peer reviewed journal "Biomass & Bioenergy".

utilization directions of biomass resources and the projected outputs of corresponding bioenergy products.

However, the above targets are only a guideline rather than a legal obligation for bioenergy industry development. To accomplish the above goals, the governments have continuously issued stepwise complementary regulations to create and promote the bioenergy market. This stepwise regulatory policy of government can be elaborated through the case of fuel ethanol.

In April 2001, a set of national standards on bioethanol's blending, storage, and delivery, i.e. "*Denatured Fuel Ethanol" (GB18350-2001)* and "*Bioethanol Gasoline for Automobiles" (GB18351-2001)*, was released, clearing the technical barriers of the introduction of bioethanol to China. Two months later in June 2001, China launched the first ever project related to bioethanol, named "*State Scheme of Pilot Projects on Bioethanol Gasoline for Automobiles*". Initially in the pilot project, three cities of Henan province (Zhengzhou, Luoyang, and Nanyang) and two cities of Heilongjiang provinces (Harbin and Zhaodong) were given mandate to run all of vehicles in the territory on bioethanol gasoline for a year. The China Petroleum and Chemical Corporation (Sinopec) and the China National Petroleum Corporation (CNPC) were the only two authorized bioethanol dispensers with the former being responsible for Henan province and the latter for Heilongjiang province. Given the success of the pilot project, in 2004 the National Development and Reform Commission (NDRC) with the help of seven other ministries implemented the *State Scheme of Extensive Pilot Projects on Bioethanol Gasoline for Automobiles*" (SSEPP) (see Figure 6-1 for more details). Under this extension, the pilot projects were launched to all cities of five provinces and several cities in certain provinces. In this round, five prefecture cities (Xuzhou, Lianyungang, Huai'an, Yancheng and Suqian) located in Northern Jiangsu are included in the trial regions. By the end of 2005, original #90, 93, 95, and 97 unleaded gasoline were mandated to be completely switched to #90, 93, 95, and 97 bioethanol gasoline (E10) and the blending rate of bioethanol was set at 10%.

Figure 6-1 Provinces/prefecture cities in China included in the "State Scheme of Extensive Pilot Projects on Bioethanol Gasoline for Automobiles" in 2004

(Source: (Dong, 2007))

Notes: Provinces and cities included in the "State Scheme of Extensive Pilot Projects on Bioethanol Gasoline for Automobiles" in 2004 are five provinces: Heilongjiang, Jilin, Liaoning, Henan, and Anhui; nine prefecture cities in Hubei province: Xiangfan, Jingmen, Suizhou, Xiaogan, Shiyan, Wuhan, Yichang, Huangshi, and Ezhou; seven prefecture cities in Shandong province: Jinan, Hezhe, Zhaozhuang, Linyi, Liaocheng, Jining, and Tai'an; six prefecture cities in Hebei province: Shijiangzhuang, Baoding, Xingtai, Handan, Changzhou, Hengshui; and five prefecture cities in Jiangsu province: Xuzhou, Lianyungang, Huai'an, Yancheng, and Suqian.

As indicated in the SSEPP, the production, distribution and consumption of fuel ethanol constitute a closed system and are under strict control. All denatured fuel ethanol must be produced by certified plants, and all E10 gasoline is distributed by either Sinopec or CNPC. So far, only four biorefineries have been authorized by the central government to produce fuel ethanol from grains, or so-called the "1st generation biofuel": Jilin Fuel Ethanol Co. Ltd., Anhui Fengyuan Biochemical, and 100,000 t from Heilongjiang Huarun Ethanol. For the Jiangsu province, the fuel ethanol is supplied from the biorefinery in Anhui. In addition, the settle price of bioethanol between fuel ethanol plants and Sinopec and CNPC was calculated as the shipping price of the #90 gasoline[1] published by NDRC multiplied by a factor of 0.9111. The market price of bioethanol gasoline was equalized to the #90 normal gasoline price published by the NDRC and may adjusted according to the gasoline market under the allowed range by government (Dong, 2007).

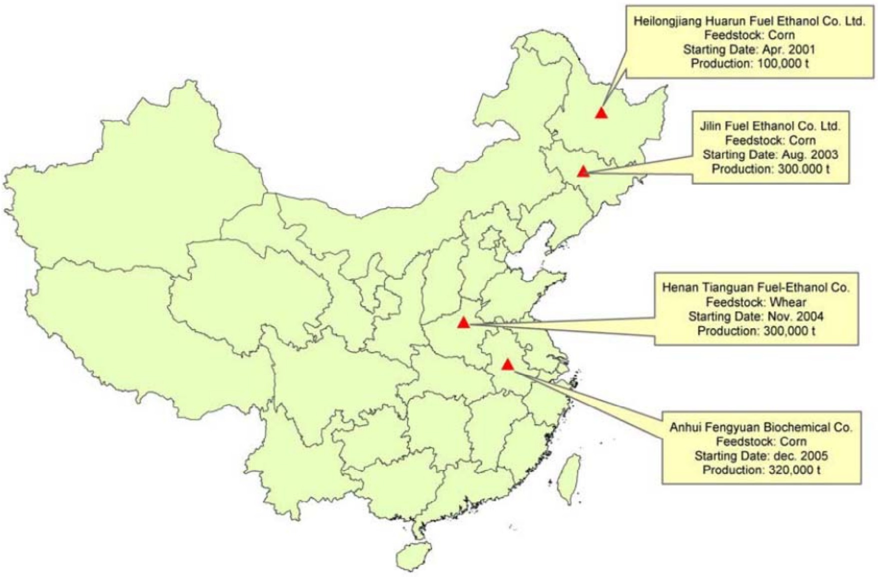

Figure 6-2 Four authorized biorefineries by central government in China

(Source: (Dong, 2007))

As bioenergy industry is both capital- and technical-intensified, the investment on the biomass conversion technology and the related devices is too burdensome for small bioenergy plants to afford. However, the investment has a significant spill-over effect to the entire industry. Out of this reason, in addition to delicately create a bioenergy market, the central government has devoted public funds to the scientific research on bioenergy. As early as in 1982, a national science and technology development plan has been designed to solve technical problems in renewable energy industry. Following that, the 863 plan (since 1986), 973 plan (since 1997)

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[1] #90 gasoline is one type of widely used gasoline in China with the octane rating at 90. The octane rating is a standard measure of the performance of a fuel. The higher the octane number is, the more compression the fuel can withstand before detonating (igniting). In China, it is calculated as the average of the RON and the MON, called the Anti-Knock Index (AKI).

and each five-year energy development plan have chosen several important but difficult topics for intensive investment. For example, in the latest *"The 12th Five-year Development Plan of Bioenergy"*, the conversion technology in lignocellulosic bioethanol production, the cultivation of new variants of energy crops and the development of powerful power generators of biogas are selected as three key research topics.

6.1.2 Policies for guaranteeing intermediate input

For bioenergy industry, the intermediate input is biomass feedstocks. According to the practical data, feedstock can account for 50%-80% of the operation costs of bioenergy plants (Jiang, Sun, 2012b, Zhang, Zhang, 2012). Hence both the state and the provincial governments have established related policies to maintain the sufficient provision of biomass feedstock to meet its increasing demand along with the industry development.

In 2007, the Ministry of Finance (MOF) issued "*Interim Management Measures of Granting Funds to the Raw Material Production Bases for Bioenergy and Biochemical*". This regulation set the subsidy level for forestry and agricultural production bases at 3,000 and 2,700 CNY/ha respectively and rules that such subsidy should be applied to the following aspects: selection and cultivation of promising variants of energy crops, land leveling and technical assistance. One year later, the MOF proposed to subsidize the straw for energy use in "*Interim Management Measures of the Subsidy of Straw for Energy Use*". In 2011, the NDRC issued "*Promoting the Comprehensive Utilization of Crop Straw in the 12th-five year*" and set the target of comprehensive utilization ratio of crop straw at 80% by 2015. Especially, the part for energy use should reach 13%. On provincial level, the local government set an even more ambitious goal of 27% in the Jiangsu province (Executive Office of People's Government of Jiangsu Province (EOPGJP), 2010). With not only promoting the utilization of crop straw, the local government has also inspired the transitional process of traditional agriculture. In the "*12th five-year Development Plan for Modern Agriculture of Jiangsu Province*", the biomass for energy purpose use has been viewed as a new agricultural economy growth engine. The annual sale of biomass resources was expected to be worth 12 billion CNY by 2015.

6.1.3 Policies for introducing value-adding actors

Bioenergy plants assume the task of upgrading the commercial value of biomass feedstock and they are the main value-adding actors of the industry. Keeping in the view of important role in the value chain of bioenergy industry, the "*Proposals for Implementation of Fiscal and Tax Supportive Policies on the Development of Bioenergy and Biochemical Industry*" proposed in 2006 offering favorable fiscal and tax measures for these actors. Generally, preferred policies for value adding actors can be divided into four types: (1) the flexible subsidy for the consumers' losses to balance the price disparity between traditional energy products and bioenergy products; (2) the subsidy for biomass feedstock production bases to stable the biomass provision; (3) the subsidy for demonstration projects to assist the implication of new technologies; (4) the partial tax exemption to enhance the competitiveness of bioenergy-related businesses.

In addition, in accordance with RELPRC, the financial institutions are encouraged to provide special capital discounts and preferential loans to the bioenergy projects that are listed in "*The National Renewable Energy Industrial Development Guidance Catalogue*". Moreover, the "*Interim Measures on Special Funds for Renewable Energy Development*" in 2006 provided bioenergy industry with interest-free or interest-low loans.

6.1.4 Policies for promoting bioenergy output

In 2006, NDRC regulated the "*Pilot scheme on renewable energy prices and cost-sharing*". According to this scheme, the on-grid tariff of biomass-based power (including agriculture & forestry residues direct combustion and gasification generation, waste incineration, landfill gas and methane power generation) is fixed by the government. The area-differentiated benchmark price is set by the price authorities of the State Council, which is calculated as the desulfurized coal electricity benchmark price for each province in 2005, plus subsidies. The subsidy for biomass-based power is 0.25 CNY /kWh since the power plants put into use and lasts for 15 years. Since 2010, the subsidy is discounted by 2% over its level in the previous year. For the biomass power generation projects selected by a competitive bidding process, government-guided prices are to be introduced and are identical to the bidding price which should not overpass the region’s benchmark price. In order to stabilize the potential investors’ market expectation and solve the problems arising in the process of executing the above scheme, NDRC has further published "*Notice on improving the policies for the prices of agricultural and forestry biomass based power generation*" by 2010. In this notice, the NDRC has adopted a uniform benchmark price at CNY 0.75/kwh for all the regions to replace the original subsidy phasing out plan. The notice, moreover, has set up a sustainable cost-sharing system of the on-grid tariff for biomass-based power. The provincial grids should pay the part identical to the local desulfurized coal electricity benchmark price and the excessive part is compensated by the renewable energy surcharge which is collected following the requirement of "*Pilot scheme on allocation of renewable energy surcharge*".

To promote the production of denatured fuel ethanol, the MOF offered the authorized four biorefineries consumption tax exemption since 2005 according to its "*Notice on the issue of tax policy related to denatured fuel ethanol production enterprises*". The existing production capacities of all plants, therefore, have been fully tapped. Along with the continuously increasing demand of bioethanol, not only the stale grains stored in the national grains reserve system have been fully used; some fresh grains are also put into use. Out of the concern over food security and to avoid conflicts between food and energy sector, the MOF has modified its preferential tax policy on biorefineries, with the emphasis on guiding them to switch their biomass feedstock from stale grains to other non-grain crops, so called the "2nd generation of bioethanol". According to the new policy notes *"Notice on adjusting the tax policy related to denatured fuel ethanol production enterprises"*, the four authorized biorefineries were ordered to resume paying the value-added tax and consumption tax since 2011. The levying ratios are initially fixed at 20% and 1% respectively and will increase by 20% and 1% year on year until the normal level is reached.

6.2 The bioenergy industry development decision support system

In pace with the governmental supports being widely adopted for the development of the bioenergy industry in China, the policy effects have gradually emerged in the practice. Some academic literature on bioenergy industry, therefore, have focused on this issue and qualitatively explored the effectiveness of these policies. In contrast, the researches conducting quantitative evaluations are far from enough, which, in turn, hinders the implementation of these policies to a larger scale.

In order to fill the gap between the practice and our perception of supportive measures as well as offer the scientists and policy makers a tool to systematically design, compare and select the most favorable policy, a bioenergy industry development decision support system (BioDSS) is set to be built in the following part of this chapter.

6.2.1 The bioenergy industry development decision support system

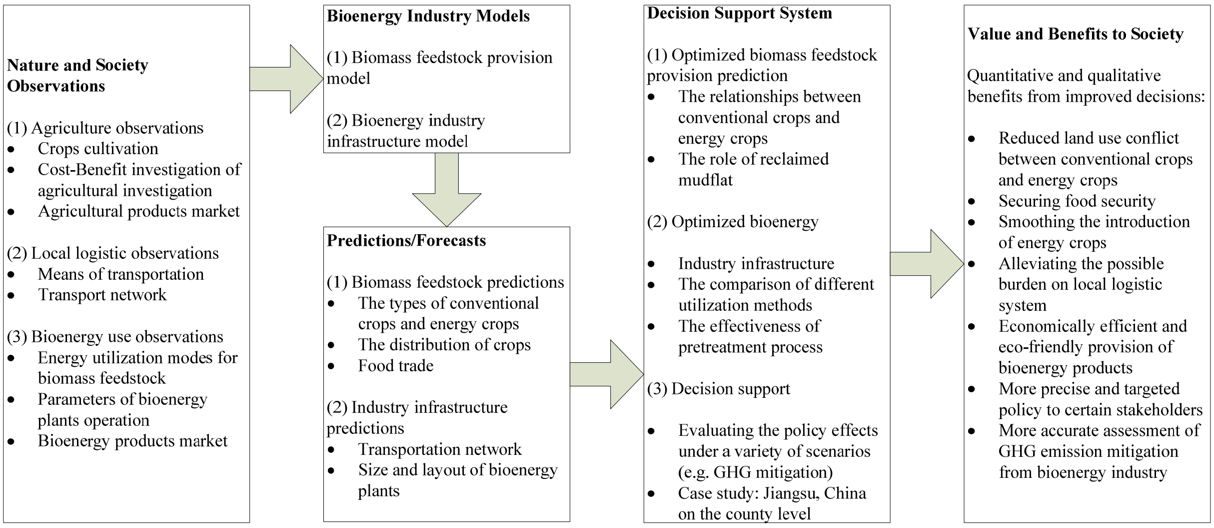

Figure 6-3 The bioenergy industry development decision support system

As is shown in Figure 6-3, the BioDSS can be constructed in four steps: (1) collecting nature and society observations relevant to bioenergy feedstock production and its utilization for energy purpose, (2) setting up two independent but related sub-models, i.e. bioenergy feedstock provision model and bioenergy industry infrastructure model, (3) conducting separate but linked scenarios through models running and (4) integrating two sub-models to form the bioenergy industry decision support system. In light of the previous two chapters having discussed the two sub-models in depth, this chapter will mainly focus on the aspect of models integration and the application of BioDSS on policy effects evaluation.

6.2.2 The integration of biomass feedstock provision model and bioenergy industry infrastructure model

To mimic their interactive behaviors in the practice, farmers, the predominating actors in bioenergy feedstock provision model, and bioenergy plants operators, the decisive agents in bioenergy industry infrastructure model are designed, in the BioDSS, to be connected via the biomass feedstock market. On this market, farmers assume the responsibility of supplying sufficient biomass feedstock, with the plants operators, on the other side, providing channels for biomass feedstock consuming. Accordingly, the two seemly independent sub-models can be integrated into a bioenergy industry development decision support system by equalizing the total output of biomass feedstock shaped in the first sub-model to the demand of biomass feedstock proposed in the second sub-model.

As a result, the biomass feedstock supply constraint the farmers originally face is internalized as a relation binding both farmers and plants operators in the integrated system. From the perspective of the operators, the pattern of biomass feedstock provision is not exogenously given anymore and can adjust to the layout of bioenergy industry infrastructures. In the new system, both the farmers and bioenergy plants operators have been entitled more flexibility to either actively or passively react to the other's behaviors. Therefore, the bioenergy industry as well as the whole social welfare is expected to benefit from this internal negotiation mechanism.

6.3 The implementation of BioDSS

After building the BioDSS, we will apply this simulation platform to assess supportive measures. In this chapter, two types of market-oriented policies, i.e. a universal taxation policy and a targeted subsidy policy, are under review.

6.3.1 The introduction of the carbon tax

Based on the estimate of bioenergy products' potentials in GHG emissions mitigation by previous studies, our research focuses on the response of bioenergy industry to carbon-based energy tax introduction. In order to testify the sensitivity of such responses, a set of carbon tax involving ten levels ranging from 100 CNY to 1000 CNY per tonne of carbon is to be introduced, comparing to a level of 10 CNY per tonne suggested to be initially executed in China (Li, 2013).

For bioenergy, a carbon-neutral renewable energy, the total amount of CO_2 emission throughout its life cycle is much less than of other traditional fossil fuels. Thus, levying an indiscriminate carbon tax on all kinds of energies is actually a "carbon subsidy" for bioenergy. In the following paragraphs, we will gauge to what extent each level carbon tax can affect the bioenergy industry. This test can provide the governments with a tangible result under each policy scenario.

In the Jiangsu province, biomass-based power and bioethanol are the two dominating bioenergy products approved by the local government. In this study, their mitigation potentials are calculated as comparing their emission amounts with the counterparts they can replace, or more specific, coal-based power which accounts for nearly 80% of nationwide electricity supply[1] and 90# gasoline which is sold in all gas stations. The emission factor of each energy product and the mitigation potentials of bioenergy products have been listed in Table 6-1.

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[1] Data source: China electric power yearbook (2000-2013)

Table 6-1 The emission factors and mitigation potentials of energy products adopted in BioDSS

Energy products[1]	**Emission factor**[2]	**Mitigation potential**[3]	**Data source**
Coal-based electricity	2600 gCE/kWh	-	Lin et al., 2008, Lin et al., 2006
Biomass-based electricity	552.80 gCE/kWh	1460gCE/kg	
90# gasoline	2298.57 gCE/kg	-	Gao et al., 2012
Bioethanol	1769.90 gCE/kg	84.59gCE/kg	

Notes: 1. The values used in our research is based on current technology. It is worth noting that the adoption of new technology in the future may significantly curtail the emission factors, for example, the large-scale application of carbon capture sequestration (CCS). 2. The value of emission factor is the amount of carbon emission of 1kg (or 1kWh) of the corresponding energy product in its whole life time. 3. The value of mitigation potential is the difference of carbon emissions between the bioenergy product generated from 1kg of biomass feedstock and the same amount of referencing fossil fuel. In the conversion process, 1.4 kg of biomass feedstock is presumed to generate 1 kWh of power and meanwhile, 6.2 t of biomass feedstock supposedly produces 1 t of bioethanol.

Table 6-2 The projection of land use change in Jiangsu province under different levels of the carbon tax in 2030

		Baseline (10^3ha)	Carbon tax levels (CNY/t.CO$_2$)[1]				
			200	400	600	800	1000
Land use pattern	Arable land in summer	2931	0.00%	0.00%	0.00%	0.00%	0.89%
	Arable land in autumn	3439	0.00%	1.05%	1.05%	1.05%	1.05%
	Mudflat	17	147.06%	417.65%	811.76%	1088.24%	1170.59%
Crop plantation area	**Conventional crops**	6370	0.00%	0.57%	-3.06%	-7.99%	-14.13%
	Wheat	2087	0.00%	1.25%	-1.63%	-5.46%	-9.54%
	Oilseed rape	844	0.00%	-2.96%	-9.60%	-18.84%	-30.21%
	Medium indiea rice	450	0.00%	0.89%	0.22%	-1.56%	-5.56%
	Non glutinous rice	2034	0.00%	0.59%	-1.62%	-5.21%	-9.88%
	Beans	248	0.00%	1.61%	-1.61%	-8.47%	-20.16%
	Corn	520	0.00%	1.15%	-2.50%	-10.19%	-20.77%
	Cotton	188	0.00%	4.79%	-17.02%	-26.60%	-32.98%
	Energy crops	17	147.06%	417.65%	1494.12%	2694.12%	4000.00%
	Switchgrass	-	-	-	-	-	-
	Miscanthus	-	-	-	-	-	-
	Silverreed	-	-	-	-	-	-
	Giantreed	17	147.06%	417.65%	1494.12%	2694.12%	4000.00%

Note: 1. The values in the columns of carbon tax levels are change rates of land use areas. They are obtained by comparing the absolute values of land use areas in different carbon tax scenarios given by the simulation results with the values in the baseline.

Table 6-3 The projected response of bioenergy industry infrastructure in Jiangsu province to different levels of the carbon tax in 2030

	Unit	Baseline	Carbon tax levels (CNY/t.CO_2)				
			200	400	600	800	1000
Biomass-based power	10^6kWh	12344	12967	14342	15480	15491	15874
Bioethanol	10^6t	1.100	1.075	1.025	1.025	1.000	0.925
Number of 15 MW power plants	-	18	18	16	12	12	12
Number of 30 MW power plants	-	13	13	14	12	12	13
Number of 45 MW power plants	-	22	23	27	33	33	34
Number of 25 000 t biorefineries	-	27	27	27	27	27	27
Number of 50 000 t biorefineries	-	9	9	9	9	9	9
Average biomass transportation distance (for power plants)	km	42	58	55	47	45	43
Average biomass transportation distance (for biorefineries)	km	41	41	50	49	38	34
Average biofuel transportation	km	61	67	64	81	80	103
Average bioslurry transportation	km	54	60	74	82	77	111
Biomass transportation frequency (for power plants)	-	47	55	51	50	47	40
Biomass transportation frequency (for biorefineries)	-	15	13	19	17	15	11
Biofuel transportation frequency	-	63	65	64	69	69	70
Bioslurry transportation frequency	-	61	63	66	66	68	71

6.3.1.1 The response of biomass feedstock production

The simulation results are according to expectations and clearly show that the introduction of the carbon tax has a positive effect on bioenergy industry, prompting both biomass feedstock supply and the successive bioenergy products output. The effect is more significant when we adopt a higher level of the carbon tax. Figure 6-4 plots two indices of biomass feedstock supply under the different carbon tax scenarios: the total production amount and the market-clearing price of biomass feedstock. Due to the inspiration of the carbon tax, the utilization scale of the environmentally friendly industry raises dramatically, with a 76% expansion of biomass feedstock supply under the carbon tax at 1000 CNY/t.CO_2. Meanwhile, the market-clearing price of biomass feedstock is nearly 2.5 times that in the baseline, implying a higher profit for the farmers and, therefore, encouraging them to produce more biomass feedstock. This judgment is demonstrated by the land use change according to the varied levels of the carbon tax, which is included in Table 6-2. In addition, the performance of a decreasing price but increasing biomass supply under the scenario of the carbon tax at 200 CNY/t can be ascribed to the participation of more reclaimed mudflats in this scenario than in the baseline, which avoids disturbing the existing land use pattern for conventional crops and secures an expanded biomass feedstock supply with holding the output level of food.

Echoing the rising momentum of biomass feedstock supply, the areas of both used arable land and reclaimed mudflat have expanded. However, their expansion tendency displays differently. In view of the crop rotation in local agriculture practice, the arable land usage can be divided into the parts for summer crops and autumn crops separately. Accordant to our simulation result, an upper limitation for land expansion can be observed in autumn crops. The competitive allocation of limited arable land resources in the season is believed to be the reason. Besides that, the seasonal differences in land use should not be ignored. In the face of energy crops' introduction, the arable land use pattern in summer is more resilient than in autumn, demonstrated by its total area keeping unchanged in the first four carbon tax scenarios. In other words, the amount of idle arable land resources in the summer can be kept and later tapped for ensuring the food security in China. As to mudflat, a candidate land resource exclusively for energy crops, the reclaimed area has expanded by 1171% in the scenario of the carbon tax at 1000 CNY/t.CO_2, due to its fairly trivial usage in baseline but tremendous potential under the pressure of large biomass demand.

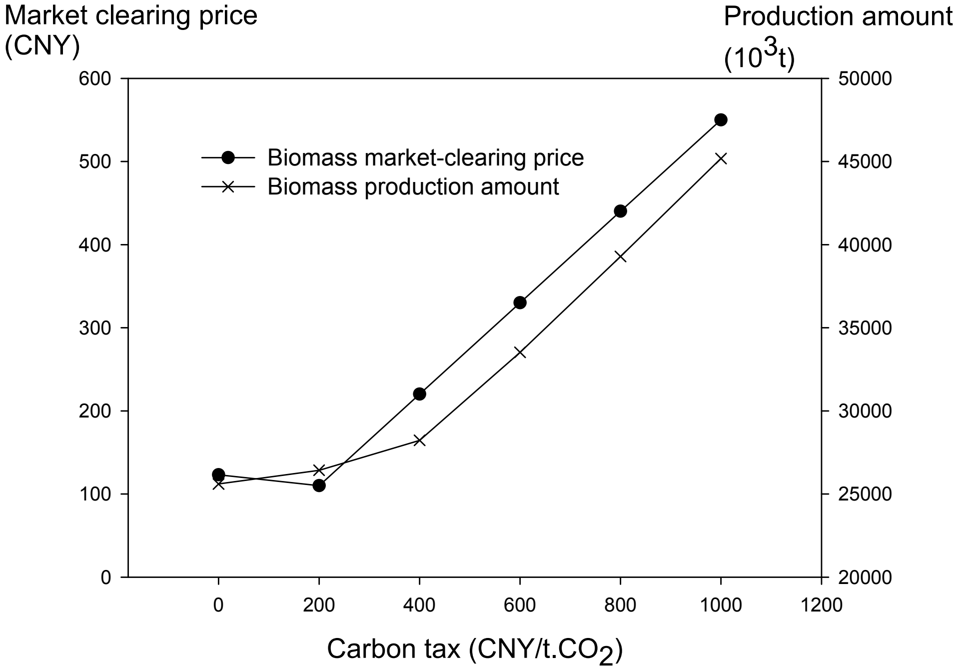

Figure 6-4 The projected response of biomass feedstock production in Jiangsu province to the carbon tax at different levels in 2030

While analyzing the composition of biomass feedstock, more information could be disclosed. By comparing the plantation areas between conventional crops and energy crops (there are 6.37 million ha for conventional crops and 16 thousand ha for energy crops in baseline), we conclude that the straw of conventional crops, as a whole, contributes the overwhelming portion of biomass feedstock. However, when the sources of the incremental part of biomass feedstock supply incurred by the rising carbon tax are decomposed, differentiated performances of the crops can be found. Among these crops, oilseed rape is strongly affected by energy crops due to its comparatively low productivity of straw, leading to a continuous contraction of its plantation area spanning from the low level carbon tax to the high level. Instead, medium indiea rice is the most preferred crop. When the plantation areas of other crops are cutting down to save lands for energy crops, the crop of medium indiea rice is still planted more widely than in the baseline. This trend does not change till the carbon tax climbs up to 800 CNY/t.CO_2. At that level, the plantation areas of all conventional crops shrink and simultaneously, the usage of reclaimed mudflat reaches the highest level. In that scenario, only giantreed is planted in the mudflat, due to its high output of biomass feedstock. In the meantime, the plantation area of giantreed has expanded to 41 times as large as in the scenario of no carbon tax.

Thus, according to our simulation, it is confident to judge that the imposition of the carbon tax on energy products can, naturally, accelerate the process of energy crops introduction as well as the reclamation of mudflat. However, in terms of its effect on food security, the tax does not necessarily place the food security in the risk. The relatively low level of the carbon tax (below 400 CNY/t.CO_2 in our model), can, on the contrary, maintain and even stimulate the cultivation of most conventional crops except oilseed rape. However, once the levying level climbs to 600 CNY/t.CO_2 or more, the impact on food production becomes negative and the extent of such impact positively correlates with the level of the tax.

6.3.1.2 The response of bioenergy industry infrastructure

Comparing the output of two bioenergy products among different carbon tax scenarios, the BioDSS shows biomass-based power has gradually gained a predominant position in two bioenergy products, thanks to its higher GHG emission mitigation potential. As is shown in Table 6-1, for the same 1 kg of biomass feedstock, the whole conversion process can produce 1460 g carbon emission less than the production of coal-based electricity, if the feedstock is processed into electricity. Meanwhile, compared to the #90 gasoline, only 84.59 g carbon emission can be curtailed if the biomass feedstock is for bioethanol production. Therefore, in facing of carbon tax introduction, the low carbon product - biomass-based power in our case- is preferred. This selective effect is expected to intensify, should the levying level of carbon tax mount.

In accordance with the shifting focus of production from biofuel to bio-power, the total installed capacity of power plants is booming, demonstrated by the soaring number of large-scale power plants at 34 under the extreme scenario. In the meantime, the capacity of biorefineries keeps unchanged although their spatial distributions are adjusting, given that the demand of bioenergy products under each carbon tax level holds the same as in the baseline.

In addition, the related transportation network has correspondingly changed. With regard to the allocation of bioenergy plants, the introduction of the carbon tax helps the biomass-based power plants to gain priority over their opponents- the biorefineries, and such dominance is even enhanced as the level of carbon tax climbs up. As can be observed from the Table 6-3, although the utilization scale of biomass for power stands increasing, the corresponding transportation scale of biomass feedstock for power plants does not synchronously rise. Oppositely, it steadily contracts from the scenario of 200 CNY/t.CO_2. This optimization of biomass transportation for bio-power is achieved at the cost of biorefineries allocation. While the power plants are given preference, the biorefineries have to, therefore, be allocated at less favorable places and thus the distance of cross-county delivery of bioethanol and its byproduct- bioslurry- has to be prolonged and occurs more frequently. In terms of the continuously downscale biomass feedstock transportation for biorefineries, the slashing output of bioethanol, meant to the cutting demand of biomass feedstock, is believed to be the reason.

However, in the differentiated reactions to the diverse carbon tax scenarios, there is one principle to be held: the bioenergy plants are suggested to be always allocated close to the biomass source regions rather than to the bioenergy products consuming centers, no matter which level of carbon tax is imposed.

6.3.2 The targeted policies towards biomass supplier and processors

As all the actors in the bioenergy supply chain contribute the GHG emissions in the production of bioenergy products, the universal carbon tax can affect them indiscriminately. But, on the other hand, we also anticipate certain types of policies which target only one actor rather than the whole. Therefore, in this part, we will examine the effectiveness of such targeted policies.

6.3.2.1 The setting of three targeted policies

Echoing the local practice, in this part we will set three targeted policies to represent the three groups of the executed policies in the Jiangsu province: the policies for guaranteeing intermediate input, for introducing value-adding factors and for promoting bioenergy output.

In the first scenario, labelled "towards bioproducts", a public financial funding is designed to subsidize the production of bioenergy products. This amount of money is set to compensate the high production cost of bioenergy products compared to the fossil fuels they replaced. In accordance with the local practice, the subsidy levels for biomass-based power and bioethanol are respectively fixed at 0.25 CNY/kWh and 750 CNY/t in our model. The second scenario, named as "towards lands", is to simulate the situation of offering subsidy to the farmers in a bid to encourage the collection of biomass from the straw of plants growing either on arable lands or reclaimed mudflats. Currently, the subsidy of 225 CNY/ha is provided to offset the extra machinery and labor cost in the collection process. The third scenario of "towards mudflats" is particularly tailored for the Jiangsu province. As reclamation of mudflats is time consuming and costly and thus, largely outweighs the expected incomes from their usage for energy crops plantations. For this reason, the total area of reclaimed mudflats in the baseline accounts for less than 1% of the used arable land. In this case, providing reclamation subsidy is believed to alleviate the financial burden of farmers and beef up the reclamation process, as well as promote energy crops' introduction. As suggested by the local investigation, the subsidy level is pinned at 30,000 CNY/ha for the year of 2011 and grows by 5% year on year.

6.3.2.2 A comparison of three policy scenarios

On the basis of simulation results from BioDSS, we conduct a simple cost-benefit analysis for the farmers, bioenergy plants operators, governments and the whole bioenergy industry. Their performances under each policy scenario have been plotted in Figure 6-5.

Besides that, in order to precisely present the responses of the bioenergy industry to different policy scenarios, other six indicators have been picked out and listed in Table 6-4. Among those, the first two indicators demonstrate the land use change in each scenario, with the following two portraying the interaction between farmers and operators and the last two depicting the output change of bioenergy products.

Table 6-4 The reactions of the bioenergy industry in Jiangsu province in different subsidy scenarios in 2030

Subsidy direction Indicators	No subsidy	Towards Bioproducts	Towards Lands	Towards Mudflat
Conventional crops cultivation (10^3 ha)	6370	6370	6370	6365
Energy crops cultivation (10^3 ha)	17	36	18	28
Biomass shadow price (CNY/t)	123	111	132	118
Biomass output (10^3 t)	25597	26202	25637	25986
Biopower (10^6kWh)	12344	12737	12370	12500
Bioethanol (10^6t)	1.100	1.100	1.100	1.125

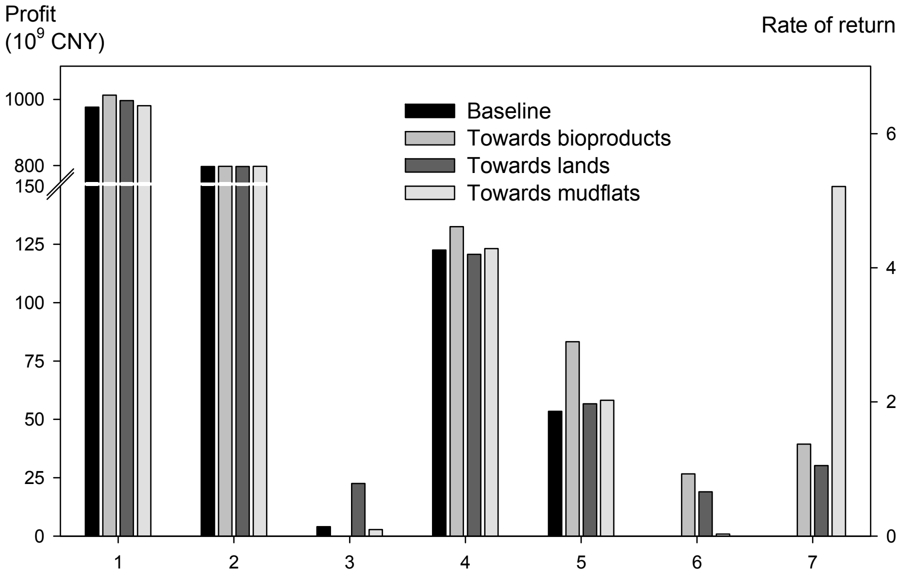

Figure 6-5 The variation of profit allocation in Jiangsu province under differentiated directions for subsidy by 2030

Notes: 1. Profits in our study are calculated as the benefits minus the corresponding costs. 2. There are seven indicators describing the profits allocation: (1) The total profit of bioenergy industry. (2) The profit from food output. (3) The profit from biomass output. (4) The profit from biorefineries operation. (5) The profit from power plants operation. (6) The total subsidy provided by the government. (7) The rate of return on targeted subsidy. 3. The units of first six indicators refer to the left Y axis and the unit of the last one refers to the right Y axis.

In general, all these subsidies can bring bioenergy industry a net profit (See Figure 6-5). Among those, the subsidy towards mudflat is most efficient, with the rate of return at 5.21. This number means each 1 CNY subsidy invested on mudflat reclamation by governments can bring the whole industry an additional profit of 5.21 CNY, much higher than the other two directions for subsidy. Furthermore, the most effective subsidy has, at the same time, the smallest scale in the three options, costing only 0.843 billion CNY for twenty years. Compared to other subsidy schemes, the financial burden of this policy is easiest for governments to bear.

Different from the last two scenarios, the subsidy on bio-products is the only targeted policy created in our model to be imposed on bioenergy plants operators. As can be seen from the indicator 4 and 5 in Figure 6-5, both kinds of bioenergy plants can benefit a lot from this supportive measure. Moreover, even the targeted policies designed for supporting farmers can also bring the operators additional profit, thanks to the policy-driven larger output of biomass feedstock allowing them to produce more bioenergy products. On the contrary, the portfolio of subsidies except for the subsidy on lands, cannot improve the economic benefit of farmers although the total output of biomass feedstock has increased among all scenarios. This seemingly paradoxical phenomenon is suggested to be the result of the unreasonably high share of reclamation cost of mudflats in the total cultivation cost of energy crops, which renders the plantation of energy crops in reclaimed mudflat unprofitable. In order to prevent this projection from realizing, offering sufficient subsidy on reclamation at the level of exceeding our simulation scenario is necessary.

Besides that, as disclosed by the model, the plantation of conventional crops is not adversely affected by these bioenergy promotion policies in terms of food security. In all scenarios except the one of "towards mudflat", the plantation areas of conventional crops are estimated to be retained at the level of 6370 thousand hectares. Even in the "towards mudflat" scenario, where there is a slight decline in cultivation areas, the profit from food output still grows, owning to the conventional crops' dual functions of offering both food and biomass.

Regarding the composition of profits, the food output constitutes the primary income source of farmers, which objectively reflects the subordinate status of the bioenergy industry in the current agriculture structure. For bioenergy plant operators, the operation of biorefineries is more profitable, due to the production of two beneficial products there, bioethanol and bioslurry.

6.4 Conclusion

Similar to other countries, China has issued a package of supportive policies to promote the development of the bioenergy industry in the face of traditional fossil fuels shortage and global climate change. In terms of the policy targets, these measures are categorized into four groups: the group for shaping a favourable external environment, for guaranteeing intermediate input, for introducing value-adding factors and for promoting bioenergy output. While these policies have largely prompted the development of the bioenergy industry, we have to acknowledge that our perception of supportive measures is still lagging behind the practices in China. One possible explanation is related to the lack of a policy analysis tool fitting to China's situation.

To eliminate this shortcoming, we build a bioenergy industry development decision support system in this chapter by integrating the two connected but independent sub-models of bioenergy feedstock provision model and bioenergy industry infrastructure model respectively set up in chapter 4 and chapter 5. Using the BioDSS, we have explored two types of bioenergy promotion policies: a universal taxation policy and a targeted subsidy. Generally speaking, both supportive measures significantly boost the development of the bioenergy industry without necessarily jeopardizing the food security.

For carbon tax, the effects positively correlate to its level, and it helps the biomass-based power plants to solidify leadership in the bioenergy market due to the larger mitigation potential of bio-power. However, the introduction of the carbon tax cannot change the principle of the layout of bioenergy plants: the bioenergy plants are always suggested to be allocated close to the biomass source regions rather than to the bioenergy products demand centers.

For financial subsidies, the one towards mudflat is preferable among three options, which has the highest rate of return and smallest scale. While all subsidies can benefit bioenergy plants operators, the subsidy towards lands cannot improve farmers' economic benefits, because of the unreasonably high reclamation cost of mudflats. In terms of the revenue sources, the food output provides the farmers the overwhelming majority of income and biorefineries are more profitable than biomass-based power plants.

Along with the breakthrough of critical biomass conversion technology, both the amount and the complexity of the information relevant to the bioenergy industry have increased, so does the problem of how to handle the information in a manner which can facilitate the development of the industry. Our BioDSS, which is created under such perception and has taken China's local practice into consideration, can be widely used to simulate the optimal supply chain of bioenergy products and assist the decision making process concerning the development of the bioenergy industry in China. Furthermore, although constructed in China, BioDSS is promising to be introduced to other countries after receiving necessary adjustment according to the target region. This platform, combined with other bioenergy simulation models, is believed to guide our practice in terms of modern bioenergy utilization in the future.

7 The sustainable development strategy of bioenergy industry in China[1]

7.1 The cascade use and recycling of biomass feedstock

The concept of circular economy was first introduced in China in 1998 and formally accepted as a new development strategy in 2002, aiming to alleviate the contradiction between booming economic development and the shortage of raw materials and energy (Yuan et al., 2006). This concept is derived from the notion of a closed loop. In other words, circular economy is to replace a linear type of the industrial chain ("resources-products-wastes") by a circular type ("resources-products-renewable resources"). In a closed loop, the "3R" principles (reduce, reuse and recycle) have to be upheld.

Following this "3R" principle, some pioneer studies have suggested the cascade utilization of biomass, which can be defined as the sequential use of original raw materials (primary crop, oilseed rape, etc.) and co- or by-products of biomass to produce materials and bioenergy (Raschka and Carus, 2012). Prior to the introduction of such a concept, biomass feedstock is treated as an energy carrier and a raw material separately, leading to the formation of two parallel utilization methods. The optimal biomass use for energy purposes, under previous conception, is achieved over only part of the biomass resource potential, rather than taking the complete sources of biomass into consideration. To the opposite, the cascading biomass use is based on respecting the various characteristics of diverse biomass sources and the different requirements for biomass with particular physical characteristics from various economic sectors (Haberl and Geissler, 2000). Therefore, a conceptual model of cascade use and recycling of biomass is proposed in Figure 7-1.

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[1] The adaptation of this chapter has been submitted to the IAS-STS yearbook (2013).

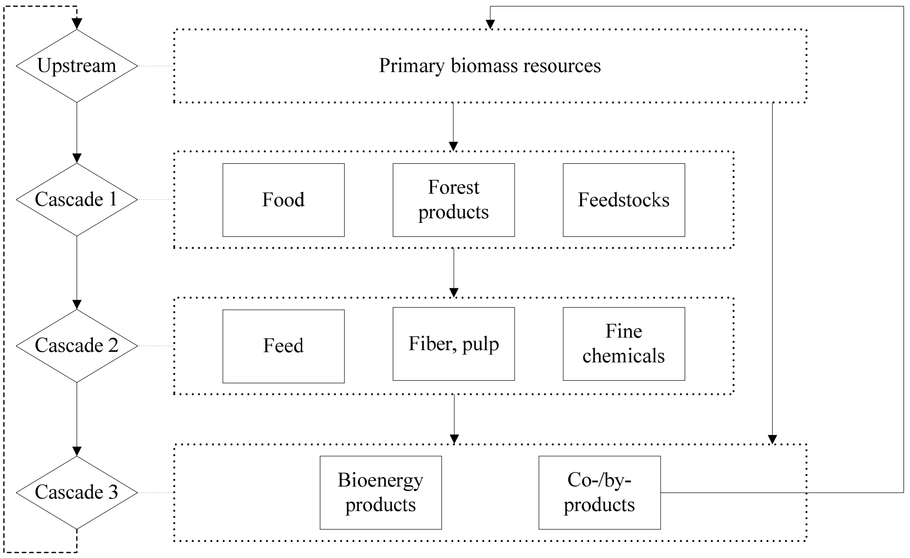

Figure 7-1 The conceptual model of cascade use and recycling of biomass

7.2 Bioenergy development policy options in China

7.2.1 Three options: Feed-in law, Renewable Portfolio Standard and Tendering policy

The current policy for bioenergy development in China is a type of feed-in law, which is regarded to be the impetus for the birth of today's modern renewable energy industry (Wiser et al., 2002). A feed-in law is a price-based policy, under which all renewable energy produced will be purchased and fed to the market at a specified price for a specified period of time set by the government (Sequeira, 2006). An alternative to feed-in law is the Renewable Portfolio Standard (RPS), which is a quantity-based policy that establishes a target quantity of each renewable energy product to be included in the respective energy market, e.g. an electricity mix by a specific date. It specifies who is responsible for supplying the renewable energy and defines penalties for non-compliance. A combination of both feed-in laws and RPS is the tendering policy. This policy is designed to find the lowest purchasing price and the eligible projects at the same time through government-overseen competitive bidding processes. To be specific, potential renewable developers are invited to submit construction schemes of new renewable production facilities and meanwhile, to indicate their expected selling prices of the energy products. The lowest priced renewable energy projects are then franchised with a guarantee from the government to purchase all the output from these projects (Wiser, Hamrin, 2002).

The above three policy options are all designed to create a market for renewable energy, each of which has specific advantages and disadvantages. Wiser et al. (2002) distinguished 11 criteria for evaluating the success of each policy implemented in the US and Europe. The assessment result is listed in Table 7-1. In general, the feed-in law is more administration-driven than RPS and tendering policy; however, the latter two options emphasize the importance of market mechanisms.

Table 7-1 Comparison of policy options to promote renewable energy development

Policy objectives	Feed-in	RPS	Tendering
Incentives for cost and price minimization	No	*	Yes
Ability to maintain targets for renewable energy	*	Yes	*
Assurance of resource diversity	Yes	No	*
Sustainable market for energy products	No	Yes	*
Political viability	*	*	*
Local industry development	Yes	*	No
Compatibility with energy industry and regulatory structure	*	*	Yes
Policy stability	Yes	No	*
Competitive parity	*	Yes	No
Integration of renewable energy supplies	No	Yes	*
Simplicity	Yes	No	No

Notes: 1 * Depends on certain conditions. 2 Adapted from: (Shen, Liu, 2010, Wiser, Hamrin, 2002)

Because each option has its specific advantages and disadvantages, there is no ‘‘ideal’’ renewable energy support policy. The favorability of these options is heavily reliant upon the policy objectives and the political context within which the decisions are being made (Wiser, Hamrin, 2002). Besides that, geographic resource capacities and different developmental stages of particular bioenergy technologies also play a critical role in choosing specific policy options (Shen, Liu, 2010).

Connecting to the local practice of bioenergy development in the Jiangsu province, it seems that the feed-in law is most likely the best policy for China and maybe for other developing countries, at least in the short term. For this judgement, we will conduct a more detailed analysis in the following section.

7.2.2 Suitable policy options for China

Based on the experiences and lessons of renewable energy development in main industrialized countries, a typical course of renewable energy development can be divided into 5 phases (see Table 7-2).

Refer to the classification criteria of the phases listed in Table 7-2, biogas and biomass-based power generation can be categorized as in phase II; the other utilization paths of biomass in the Jiangsu province (cellulosic bioethanol, biodiesel, briquette and charring) are still in the phase I. In this sense, the bioenergy market in the Jiangsu province, as a whole, is a nascent market.

Under the existing framework of the Kyoto Protocol, developing countries, including China, do not bear quantified emission limitation or reduction commitments (United Nations, 2013). At the same time, only a recommended rather than a compulsory target for renewable energy development has been adopted by China. As the RPS is lacking sufficient legitimate ground, it is currently not practicable for China. Furthermore, currently there are only two utility companies in China and the power market is highly regulated and strictly overseen by the state hence a competitive market has so far not yet developed. This is another argument against the use of RPS.

In contrast, as earlier said, the feed-in law fits China's reality better. Considering the steady

Table 7-2 Typical renewable energy developmental phases

Phase I. Research, Development and Demonstration of New Technologies
* Resource Assessment * Technology Development and Demonstration
Phase II. Wholesale Market Development
* Establishment of stable wholesale market rules and processes * Establishment of companies willing and able to undertake resource development * Establishment of manufacturing facilities * Development of a financing framework
Phase III. Cost Reduction
* Project experience (multiple projects by individual companies) * Increased manufacturing volume * Development of related infrastructure and service companies to support the technology * Standardized product
Phase IV. Price Reduction
* Assured volume/long-term opportunities * Competitive market
Phase V. Retail Market Development
* Clear market rules * Four or more individual companies * Public education/information

Data source: (Zhang et al., 2000)

increase in energy demand and an uneven distribution of renewable energy potential, China should encourage a diversity of renewable energy supply sources. Particularly, at the inception of a renewable energy system development, it is valuable to see which types of renewable energy technologies will be developed and at what cost through the market selection rather than to speculate arbitrarily by the policy maker which type will be developed within a certain price range. Feed-in tariffs appear to provide an easier mechanism of assuring diversity. First, they warrant that any form of renewable supply that can be generated at or below the feed-in tariff has a real chance of being developed. When the costs of the technologies for certain energy products decrease, the corresponding feed-in tariffs of those products can be reduced without adjusting the tariffs of other products. Therefore, both resource diversity and some economic efficiency can be achieved at the same time.

In addition, experiences in Germany, Denmark, Spain, and the U.S. show that feed-in tariffs can spur the advancement of a local renewable energy system infrastructure with benefits for local economic and industry development and employment (Rickerson et al., 2012, Wiser, Hamrin, 2002). This is one of the motives for the developing countries to promote the development of renewable energy. Different from RPS and tendering policy, which focus on immediate cost minimization, feed-in tariffs provide a short-term regulatory security to potential bioenergy investors by guaranteeing a minimum return on investment, which gains time for local actors to grow.

Furthermore, feed-in laws are more appropriate in a regulated setting in which an absolute competitive parity (the ability of a policy to spread the cost of renewable energy fairly and evenly across market participants) is not required. In comparison to RPS and tendering, the design, administration, and enforcement of feed-in tariffs are simpler. From a contractual and transaction cost perspective, feed-in tariffs with standardized interconnection requirements (a set of design requirements for output to be connected to the existing distribution system, e.g. the utility grid), contract terms, and conditions can simplify negotiations and speed the development and contracting process for renewable energy producers, which ease the market entry for financially weak and small local players to the renewable energy business (Wiser, Hamrin, 2002). From an administration cost perspective, the feed-in law generates much less administration costs for most developing countries' governments which do not have much experience on renewable energy commercialization.

The last argument that supports the feed-in tariff as an optimal instrument is its consistency with the existing laws and administrative structure. China has declared the rudimentary feed-in law as a priority while issuing the RELPRC and the " *Mid- and Long-term Development Plan for Renewable Energy*", choosing the same policy for bioenergy development which is not only consistent with the currently executing regulations, but also entails relatively low political risks.

Although feed-in tariffs and its complementary policies currently appear to have advantages over RPS and tendering policy for the Jiangsu province, there are concerns over the compatibility of feed-in tariffs with liberalization of renewable energy markets and their economic, technical and political sustainability. Several European nations consider abandoning or phasing out subsidy-based systems in favor of RPS. Similarly, U.S. policymakers increasingly prefer support market mechanisms that stimulate competition and minimize cost (Ryan et al., 2005). For the Jiangsu province as well as for other regions in China and many developing countries, the transition from an administration-led policy, i.e. feed-in tariffs, to market oriented policies, i.e. RPS and tendering, will sooner or later become necessary, due to the reason of preventing path-dependency, which means the longer we rely on administration-led policies, the more we get addicted to them, and as such the more reluctantly we switch to market-driven ones.

Unlike the feed-in law, RPS and tendering policies create price competition both between different bioenergy suppliers and between suppliers of renewable energy. By means of market power, renewable energy generators are pressed to continuously lowering their costs through economies of scale and gaining project development experience. Thus, through the implementation of market-oriented policies, the driving force of industry development is internalized. In other words, the bioenergy industry can step towards the track of sustainable development in its own strength rather than by the outside force, e.g. the administrative power.

Moreover, as RPS is competitively neutral, it can avoid unjustified welfare shifts from some sorts of renewable energy to others. With a well-designed credit trading system under an RPS, the incremental costs of energy products can be spread fairly across the market participants. Additionally, if integrated with other economic, environmental and resource development goals, the credit trading system can help to reduce the economic gap between the three sub-regions of the Jiangsu province.

7.3 The discussion of development strategy of bioenergy industry in China

To answer the question of why particular industries become competitive in particular locations but others are not, Michael E. Porter (1990) creatively built an analytic paradigm to explain the national competitiveness, named the diamond model (Figure 7-2). He examined several hundred types of industries of eight advanced countries (the US, UK, Sweden, Japan, Italy, Germany and Denmark) and two new industrialized countries (South Korea and Singapore) and found that four determinants (factor conditions, demand conditions, related and supporting industries and firm strategy, structure and rivalry) and two auxiliary factors (government and chance) constitute the elements of competitiveness. The name of the diamond model is derived from the outline of the network formed by the interactions between these variables. Here we borrow this model to discuss the ways of cultivating bioenergy industry's competitiveness.

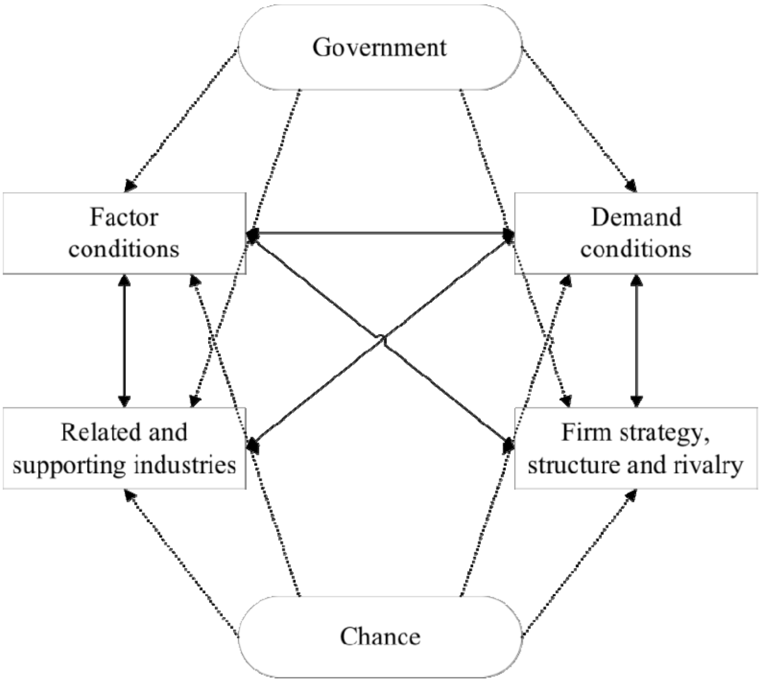

Figure 7-2 Porter's diamond model - the determinants of national advantage (Porter, 1990)

FACTOR CONDITIONS: Porter divided factor conditions into primary and advanced production factors. For bioenergy industry, primary production factors refer to the basic proven reserves of biomass resources in China. Unfortunately, the nationwide potential of biomass resources is still unclear, although the rural areas have the tradition of using biomass for heat and cooking for several thousand years. In this sense, conducting a survey on biomass resources to clarify the possible sources of biomass feedstock, as well as the potential for each source and its distribution, is not only necessary but also urgent. As to advanced production factors, human resource is a critical one. Compared to primary factors, the bioenergy researchers and trained workers, who are professionals in the operation and management of bioenergy, cannot be cultivated in a short time but require continuous and a considerable amount of investments lasting for a relatively long period.

DEMAND CONDITIONS: According to the sources, bioenergy demand can divide into domestic demand and global demand. Due to biomass' natural attributes of low energy density and irregular shapes, long-distance transport of bulky biomass in reality is not much profitable. For this reason, the domestic market, especially a local market, contributes the predominant part of the demand. From the perspective of economics, the conception of market includes three components, i.e. market structure, size and growth. Among them, bioenergy market structure can be further divided into biochemical conversion (biogas and fuel alcohol), biomass gasification (power generation or thermal power coproduction), biomass liquefaction (biodiesel) and direct burning (boiler burning, dense burning and garbage burning). In all possible utilization methods, the scale of biomass power generation ranks the 1st, and the installed capacity reached 5.5 GW by the end of 2010, generating electricity of 33 billion kWh. Following power generation, the annual output of biogas was about 10 Mtce. Biomass liquid fuel (bioethanol 1.8 Mt and biodiesel 0.5 Mt) and biomass solid fuel (3 Mt) ranked the 3rd and 4th respectively (China National Development and Reform Commission (CNDRC), 2012). In favor of the economy of scale brought by the concentrated utilization, large-scale production of bio-power and bioethanol are preferred by the Chinese governments. In view of the technology-intensive and capital-intensive production process, governments have even proposed targeted fiscal and tax policies to prompt the applications of bioenergy products.

In addition, the overseas market, as a complementary but emerging market, is also worth paying attention. Given the highly competitive leaders in the international bioenergy industry, the advantage of China's bioenergy industry is not distinct. Therefore, before participating in the international competition, the industry in China needs to achieve a major breakthrough in several critical fields, for example, the research on bio-enzyme widely used in the cellulosic biofuel production.

RELATED AND SUPPORTING INDUSTRIES: Porter claims that for a single firm or a single industry, it is hard to keep its competitive edge; and that only by forming effective industrial clusters and stimulating active interactions between upstream and downstream of the industry can the competitive edge be retained. This rule can also be applied to the bioenergy industry. Due to the varying sources of biomass feedstock, the bioenergy industry has a close connection with many other industries and thus leads to the formation of an industrial cluster (Figure 7-3).

The industries having backward linkages to the bioenergy industry are agriculture, forestry industry and machinery manufacturing industry, which offer bioenergy industry either biomass feedstock or machineries. Since the energy purpose of biomass resources is introduced, the cultivation and harvest methods as well as the machineries used in different stages are about to change correspondingly. The industries that have forward linkages to the bioenergy industry are automobile manufacturing industry and transportation industry as these industries consume the bioenergy products. The bioenergy industry can affect the development directions of these downstream industries and broaden their application scopes and scales. These downstream industries, in turn, will propose higher standards to the bioenergy products in the face of competition. This mutual feedback provides the bioenergy industry with an endogenous momentum for developing and, therefore, helps the industry to shape its competitiveness in the energy portfolio.

Along with the supply chain of the bioenergy industry, the industries having lateral linkage to the bioenergy industry are:

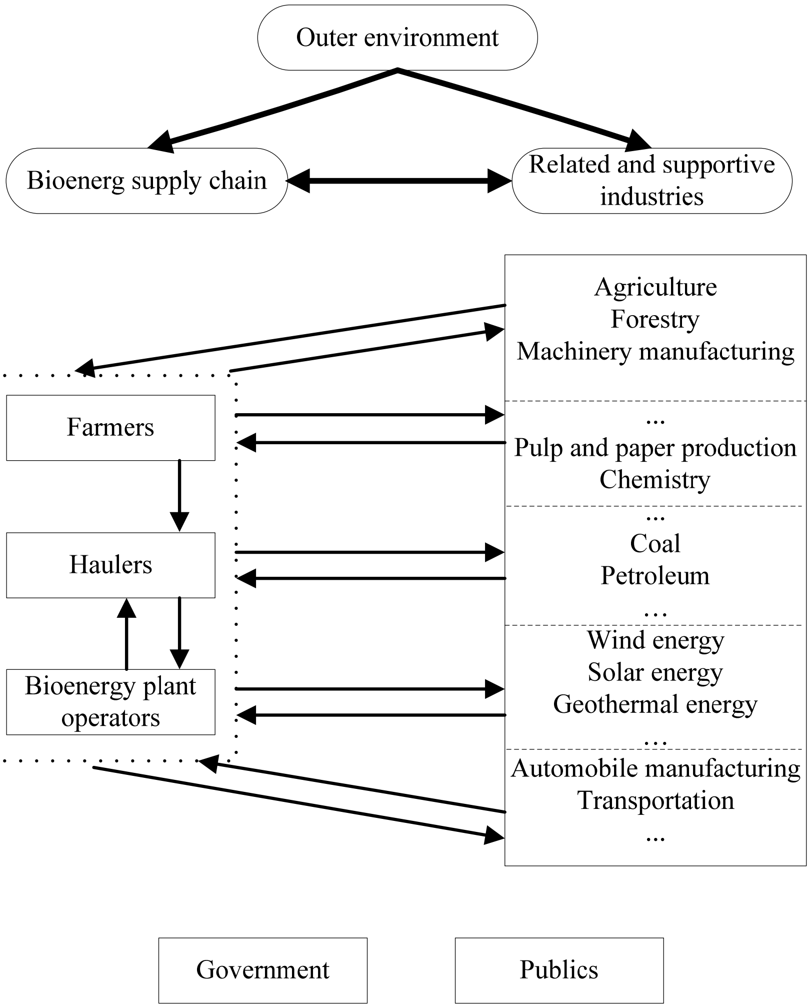

Figure 7-3 The industrial cluster with bioenergy industry centered

(1) The ones sharing the same primary biomass resources. They are pulp and paper production industry and chemical industry. Initially, the competition among them for the biomass feedstock appears to be unavoidable. However, under the guidance of the principle of the cascade use of biomass, the by-products and sludge in pulp and paper production industry and chemical industry can be used as feedstock for the bioenergy industry. Thus, the conflicts between these industries can be relieved.

(2) The industries sharing the same renewable energy market. The wind energy, solar energy, geothermal energy, tidal energy may, on the one hand, compete with the bioenergy industry for the limited market capacity and supportive funds from governments. However, on the other hand, a "promotion effect" from the combination of renewable energies could also be

observed, as these energies share the same policy environment, have geographically differentiated potentials and use different but related technologies. All of these facts indicate that the competition among these renewable energies is not a zero-sum game, and that the bioenergy industry can probably benefit from this competition.

(3) The industries sharing transportation resources, for instance, the coal industry and petroleum industry. One distinctive feature of bioenergy, compared to most other renewable energies, is the mobility of its energy carrier. While offering the advantage of stabilizing energy supply on a larger temporal and spatial scope, bioenergy aggravates the competition for valuable transportation resources, i.e. the competition for haulers, vehicles and road resources. To reduce to a minimum the disturbance of biomass and bioenergy delivery on the existing transportation network, an appropriate layout of bioenergy industry infrastructure as well as adopting densification process for biomass feedstock are essential.

To sum up, the development of bioenergy industry is not an isolated, but a comprehensive issue, which needs to take the entire bioenergy industry cluster into consideration and especially, value the role of synergy.

FIRM STRATEGY, STRUCTURE AND RIVALRY: this is a triangle relationship of corporative governance proposed by Porter. It covers the topics like how to found, organize and manage firms, how to face the rivals. Firms, as the micro-organizations in the industrial system, play a fundamental role in the formation and development of industries. For bioenergy industry, professional bioenergy firms enjoying definite property rights, perfect governance mechanisms, advancing technological background and efficient management methods should be the basic actors making up the bioenergy industry. In compliance with the market mechanism and the related governmental support, they are led to efficiently allocate the input capitals, adequately invest on critical technologies, sufficiently provide bioenergy products and in the end, to optimize both social benefits and economic benefits of the bioenergy industry.

CHANCE AND GOVERNMENT: Porter points out that as auxiliary factors, chance and government cannot function independently other than through influencing the above four determinants.

In the face of the soaring energy demand and the volatile energy markets, the traditional development path of human society, which heavily relies on fossil fuels, has come under strong criticism. Searching for alternative renewable energies is not only a key to solving the current problem. More importantly, it represents a totally new development strategy. In the meantime, the side effects of excessively using fossil fuels have emerged. Out of the concern over climate change, a line of treaties dealing with controlling GHG emissions are signed by the international community. Under this circumstance, bioenergy, as a feasible solution to both fill in the demand gap left by fossil fuels and contribute to the GHGs emission mitigation, has obtained an unprecedented opportunity for its development.

Government is the last element in the diamond model. It can influence the supply conditions of critical production factors, demand conditions in the home market, and competition between firms and industrial clusters on a higher level. Integrated with the reality of China, the governments there are supposed to assume the triad of responsibilities.

The first responsibility is supervisory duties. The governments should supervise rather than personally participate in the bioenergy industry. In the meantime, the management methods of the government have to follow the intrinsic features of the bioenergy industry. Particularly, each actor constituting the bioenergy industry should match with a specific administrative department. Therefore, the authors suggest setting up an inter-departmental council composed of agriculture, land, industry and business, technology and environmental protection ministries so as to smooth the communication between the different sections of the bioenergy industry.

The second one is legislative duties. Compared to conventional energies, the bioenergy industry is relatively nascent, and a mature bioenergy market has not completely formed. In order to offer bioenergy industry a favorable development environment and meanwhile prevent the unfair competition from traditional energies by using their predominant status in the existing energy market, the status and the share of bioenergy in the future energy portfolio need to be clarified and ensured by laws. Therefore, a periodically nationwide investigation on biomass resources legislated in RELPRC is necessary to obtain the first-hand and up-to-date data of biomass potential from each source. Based on the updated information, we suggest the NDRC to compile a bioenergy industry development plan within the framework of the five-year development plan. The consistency of this industry development plan with other plans focusing on the related and supported industries should specially be paid attention.

The last one is its responsibility to provide favorable incentives. As an emerging industry having high positive externality to the human society and natural environment, the support from governments is justified. In accordance with the hierarchical administrative system, a set of top-down supportive measures covering all actors of the bioenergy industry should be designed. However, although the governmental interference at a reasonable scale can correct the market failure and assist the improvement of nascent industries, the market-oriented policies in general are preferred. Besides of offering subsidies, the governments bear other responsibilities, such as consolidating fund-raising channels for the firms, constructing the risk early-warning system and assisting the demonstrative projects.

In conclusion, the overarching guideline for the government on cultivating the industry's competitiveness is to construct a favorable market circumstance and respect the predominant role of bioenergy firms in the bioenergy industry.

7.4 Conclusion

After constructing a comprehensive simulation platform of decision support for bioenergy industry development, this chapter returns to the primary question proposed at the beginning of our research, i.e. what is the sustainable development strategy of the bioenergy industry in China. To answer this question, we should not only focus on the industry itself but adopt a temporarily and spatially broad viewpoint to examine the relations between the bioenergy industry and the relevant factors, the latter of which, as a whole, compose the external atmosphere of the industry.

Echoing the principle of sustainability, this chapter firstly proposes a conceptual model of cascade use and recycling of biomass derived from the notion of circular economy and emphasizes the coordinated utilization of biomass as an energy carrier and as a raw material.

Subsequently, the focus is moved on to the different but related features of incentive mechanisms in the short and the long term. We argue that the adoption of administration-driven policy, i.e. feed-in law, is currently more realistic for China than market-oriented policies, such as RPS and tendering policy. The reason is that in China, a mature competitive renewable energy market has not yet formed. Meanwhile, the motive of correcting the market failure incurred by positive environmental externality of renewable energy projects has also justified our suggestion. Nevertheless, the potential side effect of governmental intervention on the development of a competitive market in the long term cannot be ignored. In the future, the transition process from feed-in tariffs to RPS and tendering is unavoidable.

In the end, by using Porter's diamond model, this study discusses the comprehensive strategy of cultivating bioenergy industry's competitiveness. Particularly, four determinants including factor conditions, demand conditions, related and supporting industries and firm strategy, structure and rivalry and two auxiliary factors covering government and chance have been examined. We argue that an unprecedented opportunity for bioenergy industry development has come. The fundamental actors driving the development of the industry are professional bioenergy firms boasting clearly defined and well-enforced property rights, good supervision mechanisms, advanced technological background and effective management methods. Since the bioenergy industry is mostly oriented towards the domestic market, it is likely to become more competitive with the formation of an industrial cluster focused on bioenergy or by receiving appropriate support from the government. The government's intervention is justified in this context by the government’s supervisory duties, legislative duties and its responsibility to provide favorable incentives.

Different from most accessible literature about the construction of the bioenergy industry in China, this research tentatively introduces a prestigious analysis tool in the field of the industrial economy to decompose the competitiveness of the bioenergy industry. Although the analytical paradigm in this chapter has only applied to the industry in China, it can also be applied to the industry in other countries. In the future, a comparative study on this industry among the advanced and emerging economies could become a new research topic.

7.5 Research limitations and outlook

In this study, we have successfully built an integrated model covering all the actors of the bioenergy industry and proposed a sustainable development strategy for the industry in China. Nevertheless, the study has several limitations that need be overcome before it can be extended to other regions.

Firstly, there are uncertainties in this study. Uncertainty in analysis processes reflects the incomplete knowledge of the system or limited capacity of available hardware (e.g. computing capacity). Due to the lack of high-quality field data of energy crops plantations, the uncertainties regarding actual agricultural operations and the resultant potential ecological risks cannot be fully reflected in our study.

Secondly, only bioethanol and biopower have been included in the mathematical model. In order to improve the coverage of the model, more biomass conversion routes should be included in future models.

Therefore, further research can be conducted from the points listed below:

(1) To include more environmental factors. In the simulation of biomass feedstock provision, we can introduce more the environmental factors, such as soil erosion, nitrogen, and phosphorous movements so as to improve the weight of environmental issues in our model.

(2) To adopt high-quality data of energy crops plantations and biomass conversion routes. Along with the accumulation of the practical experience from our study area, more first-hand data can be collected. The use of high-quality data will significantly improve the scope and precision of our model.

(3) To adopt more natural resources. Due to the high extensibility of the BioDSS, in the coming studies, we can introduce other natural resources, for example, water resources, forestry resources and grassland resources into consideration.

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Appendix A An overview of the field trip

I conducted a field trip to the study area of this research- Jiangsu province in China- between February 15 and March 15 in 2012. In the 30-day trip, I visited Beijing, Nanjing, Huai'an, Suqian and Yancheng and mainly collected three types of data:

- Literature data
- Land use and land cover map, the types, cultivated area, yield of crops, total arable land area, ArcGIS file of the transportation system, (the irrigation and tillage method, the utilization of mechanical equipment, pesticide and fertilizer)
- Local data
- The costs (including direct, power and overhead) and benefits of each crop, the local situation of mudflat, the demand amount of dry matter, national incentives and limitations of bioenergy, transportation costs for biomass and its products, costs of existing bioenergy plant (including annualized fixed cost, processing cost and other costs)
- Interviews data
- The perspectives of stakeholders of bioenergy industry, including farmers, haulers, plant operators, governments, NGOs, local residents and public

In order to obtain a complete picture of the bioenergy industry in Jiangsu province, I designed eight kinds of administrative bodies (research institutes, industry associations and companies) to be visited, corresponding to each section of the supply chain of bioenergy products. The detailed interviewees are listed in Table A.

Table A Overview of the interviewees

Field	Name	Title	Institutes/ organizations
Food crop plantation	Shi	General manager	Nanjing Pukou Tangquan Farm
	Shu Yu	Staff	Jiangsu Province Statistic Bureau
	Guanghua Wang	Director	Cost Price Investigation and Supervision branch, Jiangsu Commodity Price Bureau
	Shulin Guo	Director	Agriculture centre, Jianggang Farm
	Zhu	Dean	Jiangsu farms agribusiness company
Crop straw utilization			Energy division, Jiangsu Development and Reform Commission[1]
	Yuting Qian	Staff	Rural energy division, Jiangsu Province Commission of Agriculture
Energy crop plantation	Yong Xu	Deputy director, Vice Prof.	Institute of Biochemical Engineering, Nanjing Forestry University
	Xiaohua Long	Vice Prof.	Research Institute of Biomass Energy, Nanjing Agriculture University
	Zhaohong Fang	Deputy general manager	Jiangsu East Lake Bioenergy Plant Garden
Mudflat reclamation	Hongyou Chen	Director	Jiangsu Agricultural Resources Development Bureau
	Shen Lin	Prof. Deputy director	Institute of Jiangsu Costal development research, Yancheng Normal University
Biomass transportation	Li	Director	Provincial Road Bureau, Jiangsu Transportation Department
			Shanghai Railway Bureau, Nanjing Branch[1]
Biopower	Wenchun Cui	Director	Energy division, Suqian Development and Reform Commission

	Chen	Engineer	Suqian Kaidi Green Energy Development Co., Ltd.
	Chun Tian	Office director	Huai’an Guoxin biomass power company
	Xinhai Gu	Staff	Jiangsu Electric Power Association, Biomass Power Generation Branch
Bioethanol	Peng Xiong	Board Chairman	Huai’an Baimai Green Bioenergy Co., Ltd.
Biodiesel	Yunjuan Sun	Dr.	Bioenergy and Materials Key Laboratory, Research Institute of Forestry Chemistry, Chinese Academy of Forestry Science
	Xu	General manager	Jiangsu Qianglin Bioenergy CO. LTD.

Notes: 1. These interviewees were contacted via Email. In such case, no contact person was listed here.

Appendix B Impression from the field trip to Jiangsu province

(Left) The view of local farmland

(Right) The front gate of Jianggang Farm

(Left) The first demonstrative production line of bioethanol in the Jiangsu province

(Right) The byproduct of bioethanol- bioslurry

(Left) The storage area of biomass feedstock

(Right) The smashed biomass feedstock

(Left) The feedstock feeding to furnace for power generation

(Right) The biopower feeding to grid

(Left) The pool for incineration residue

(Right) Photographed with interviewee, the general manager of Huai'an Baimai Green Bioenergy Company

(Left) Photographed with the interviewee, Prof. Shen Lin from Institute of Jiangsu Costal development research, Yancheng Normal University

(Right) Photographed with the interviewee, Director Hongyou Chen from Jiangsu Agricultural Resources Development Bureau

Appendix C Short resume

Kesheng Shu, studied Geology at the China University of Geosciences, Economics at Wuhan University, and Human Geography at the Institute of Geographic Sciences and Natural Resources Research of the Chinese Academy of Sciences. In his master thesis, he discussed the population carry capacity of the upstream regions of the Yangtze River. Since September 2010, he is a PhD student at the Research Group Climate Change and Security (CLISEC) at the Institute of Geography, University of Hamburg. He focuses on modeling the development of bioenergy industry in the context of climate change.

Research Interests

- Natural resources management modeling and policy analysis
- Climate change adaptation and mitigation
- General algebraic modeling system (GAMS)

Selected Paper Publishing:

1. K. Shu, A. Uwe, J. Scheffran, Bioenergy and land use: a spatial-agent dynamic model of optimized agricultural land use to Jiangsu in China, The 12th IAS-STS Annual Conference 2012.
2. K. Shu, J. Scheffran, A. Uwe, Bioenergy for sustainable development in developing countries - A Jiangsu prospective, The 32nd International Geographical Congress 2012.
3. K. Shu, M. Huo, Discussion of the Chinese Development Strategies of Geothermal Resources Based on the Circular Economy, World Geothermal Congress 2010.
4. K. Shu, M. Huo, Application of Remote Sensing Technology in Geothermal Exploration: a case study of Taizhou city in Jiangsu province, World Geothermal Congress 2010.
5. K. Shu, The research on the Division of the Development Priority Zones on the Basis of Relative Carrying Capacity of Resources Information：a case study of the Yangtze River Basin, Areal Research and Development, 1(2010),33-37.

Selected Practical training:

08.2014- 01.2015, Teaching assistant, Hamburg University
10.2013- 03.2014, Research assistant, Hamburg University
10.2012- 06.2013, Visiting scholar, Institute for advanced studies on science, technology and society (IAS-STS), Graz, Austria
04.2012- 03.2014, Activities coordinator, PIASTA, Hamburg University

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